APPENDIX D

Water Quality Modeling Methodology and Results

2006

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APPENDIX D
WATER QUALITY MODELING METHODOLOGY AND RESULTS

The Salton Sea is a terminal, saline lake located in the southeastern corner of California and within one of the most arid regions in North America. The Salton Sea is the largest lake in California, measuring about 35 miles long and 9 to 15 miles wide with about 360 square miles of water surface area and 120 miles of shoreline. The Salton Sea lies in a geographic depression with the lowest point about -278 feet mean sea level (msl). The water surface elevation estimated on January 1, 2005 was -228.7 feet msl (USGS, 2005). At this elevation, the Salton Sea has a maximum depth of about 50 feet, an average depth of about 30 feet, and water storage volume of about 7,200,000 acre-feet.

The current Salton Sea was formed during 1905 to 1907 as a result of an uncontrolled diversion of the Colorado River (Ogden, 1996; Hely et al., 1966). The water surface elevation of the Salton Sea rose to a maximum of -195 feet msl when the diversion dike was repaired in 1907, but rapidly receded to about 250 feet msl in 1925, as evaporation exceeded the rate of agricultural drainage flows. In 1925, the elevation of the Salton Sea started to increase due to increased discharge of drainage from agricultural areas in Imperial, Coachella, and Mexicali valleys. Drainage flows from these areas have generally sustained higher water surface elevations since then.

The Salton Sea is saline due to the accumulation of salts left behind through evaporation. The Colorado River is estimated to have had an average salinity of about 500 milligrams/liter (mg/L) total dissolved solids (Hely et al., 1966). The large amount of salts that had accumulated in soils from previous inundations in past centuries rapidly dissolved into the fresh water when the basin flooded in 1905 to 1907. This dissolution of salts, combined with high evaporation rates and minimal inflows, caused the salinity to quickly rise to above 40,000 mg/L by 1925. The salinity decreased in the late 1920s, as irrigated agriculture expanded and resulted in greater drainage flows to the Salton Sea. During the 1930s, agricultural activity declined, and salinity increased to more than 43,000 mg/L. As agricultural activities increased in the 1940s and 1950s, the Salton Sea salinity increased to more than 40,000 mg/L (Hely et al., 1966; Tostrud, 1997; Holdren, 2005).

In addition to the effects of increasing salinity, several other factors affect the long term water quality of the Salton Sea. The Salton Sea is a hypereutrophic water body characterized by high nutrient concentrations, high algal biomass as demonstrated by high chlorophyll *a* concentrations, high fish productivity, low clarity, frequent very low dissolved oxygen (both hypolimnetic and epilimnetic), fish kills, and noxious odors (Setmire et al., 2001). High levels of nutrients from agricultural drainage and municipal discharges, combined with warm temperatures, contribute to extremely high levels of productivity in the Salton Sea. The high productivity has contributed to a number of impairments to water quality, including nuisance algal blooms, anoxia, and production of hydrogen sulfide and ammonia with detrimental effects to fish. The hypereutrophic condition of the Salton Sea is believed to be controlled, or limited, by phosphorus concentrations.

This appendix describes water quality modeling for the Draft Programmatic Environmental Impact Report (PEIR). The principal goals of this appendix are (1) to characterize the recent water quality conditions and processes at the Salton Sea through preliminary modeling and (2) to prepare estimates of future Salton Sea water quality conditions under a range of alternatives and nutrient loading scenarios. The data sources, methods, and results are discussed in detail in the following sections. Since significant uncertainty exists regarding water quality data and processes, the water quality modeling analysis was performed to provide comparative evaluations of various alternative configurations and conditions being considered in the PEIR. This appendix describes the water quality data, modeling of restoration alternatives, general conclusions and limitations, and future needs to address the water quality of the Salton Sea. The focus of this study is toward improving understanding of the nutrient dynamics that are most critical to ecosystem restoration efforts. Other water quality parameters, such as selenium and its associated ecosystem risks, are discussed in Appendix F and not included in this appendix.

SUMMARY OF EXISTING DATA AND SOURCES

Previous investigations have characterized the water quality at the Salton Sea and have studied the mixing and nutrient dynamics which govern the high productivity (Setmire et al., 2001). Despite extensive study of the Salton Sea water quality, significant data gaps exist (both in extent and quality) and inconclusive understanding of key processes remain. Significant long term water quality data are needed to better understand water quality processes and help narrow scientific disagreements on the relative importance of various mechanisms that load nutrients to the water column and contribute to oxygen demand. The sections that follow briefly describe the available data and sources that were incorporated into the modeling for the Salton Sea.

Physical Characteristics

The long, or primary, axis of the Salton Sea runs northwest to southeast in approximate alignment with the principal axis of the Coachella Valley. The geometry of the Salton Basin and the meteorological conditions (high winds and temperatures) strongly influence the hydrodynamics and water quality of the Salton Sea.

Bathymetry

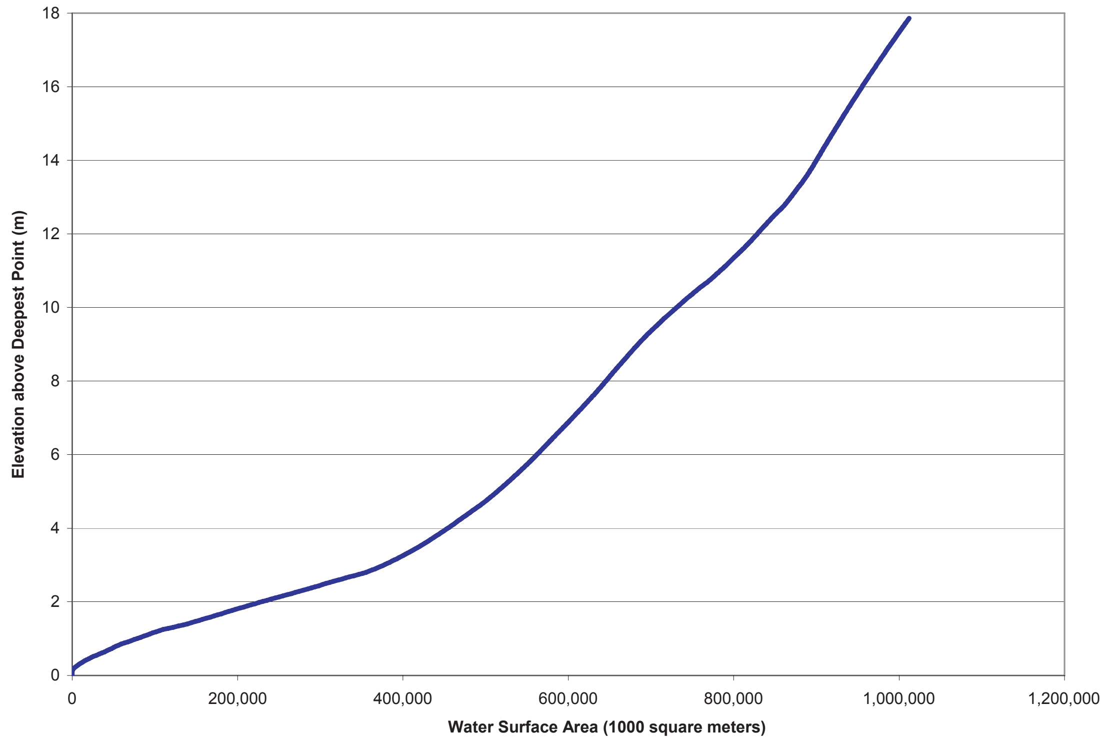
A bathymetric survey of the Salton Sea was conducted by the U.S. Department of Interior, Bureau of Reclamation (Reclamation) in 1995. The Salton Sea contains two subbasins separated by a shallow saddle in the middle. The bathymetry exhibits relatively flat areas along the southern, southwestern, southeastern, and northern shorelines, and the steepest slopes along the northeastern shoreline near Salton Sea State Recreation Area. The elevation of the two deepest points in the north and south subbasins are about -278 feet msl.

These bathymetric data were used to generate tables relating elevation, surface area, and capacity for use in the water quality modeling. The bathymetric from which the relational tables were created was generated from a Triangulated Irregular Network through the ArcGIS software. These elevation-area-capacity curves are shown in Figure D-1.

Meteorology

Meteorological data for California are available from the California Department of Water Resources (DWR), Office of Water Use Efficiency, California Irrigation Management Information System (CIMIS). CIMIS currently includes over 125 active weather stations located throughout the State, as well as 61 inactive stations for which historical data are available. The stations measure a number of meteorological parameters, including solar radiation, air temperature, soil temperature, relative humidity, wind speed, wind direction, and precipitation. Additional parameters are calculated based on the measured values and include net radiation, reference evapotranspiration, wind roses and wind cubed (an indicator of wind power), vapor pressure, and dew point temperature (DWR, 2005).

Data from five CIMIS stations near the Salton Sea are available for 1999 and were used in characterizing its meteorological conditions. These stations include (from north to south) #136 (Oasis), #141 (Mecca), #154 (Salton Sea North), #127 (Salton Sea West), and #128 (Salton Sea East), as shown on Figure D-2. The hourly wind speed, direction, and frequency at each of the CIMIS stations are illustrated through the "wind rose" diagrams shown in Figures D-3, D-4, and D-5. The frequency of winds blowing from



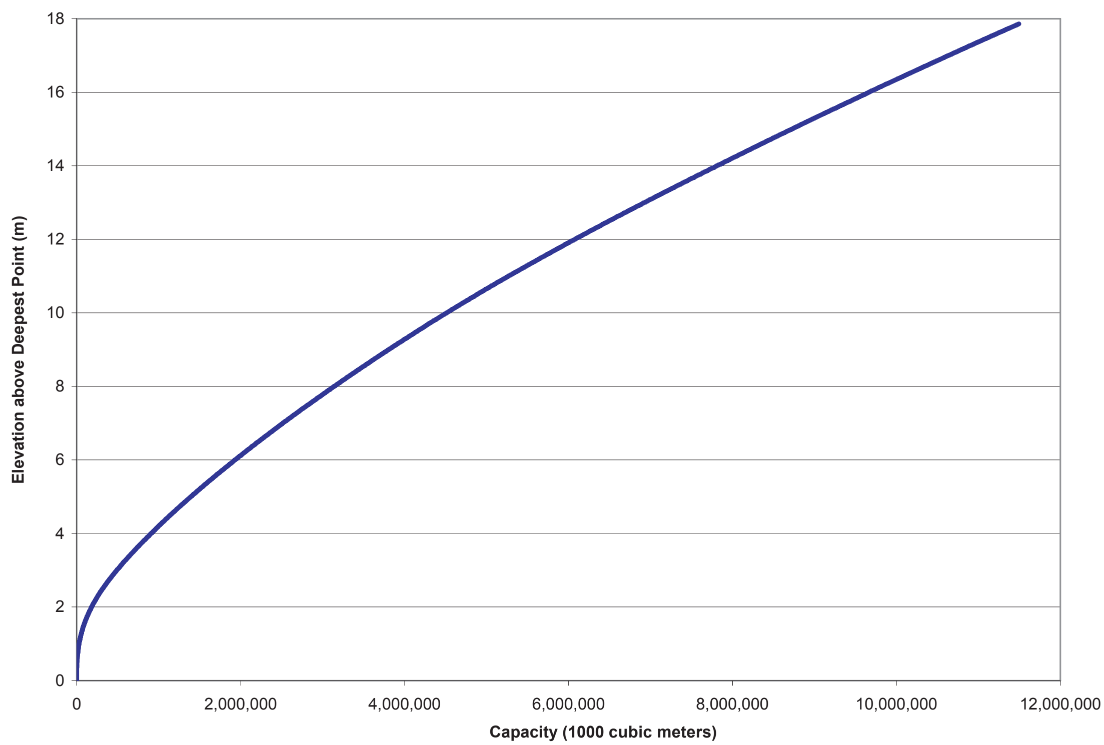


FIGURE D-1
ELEVATION-AREA-CAPACITY CURVES FOR THE EXISTING SALTON SEA

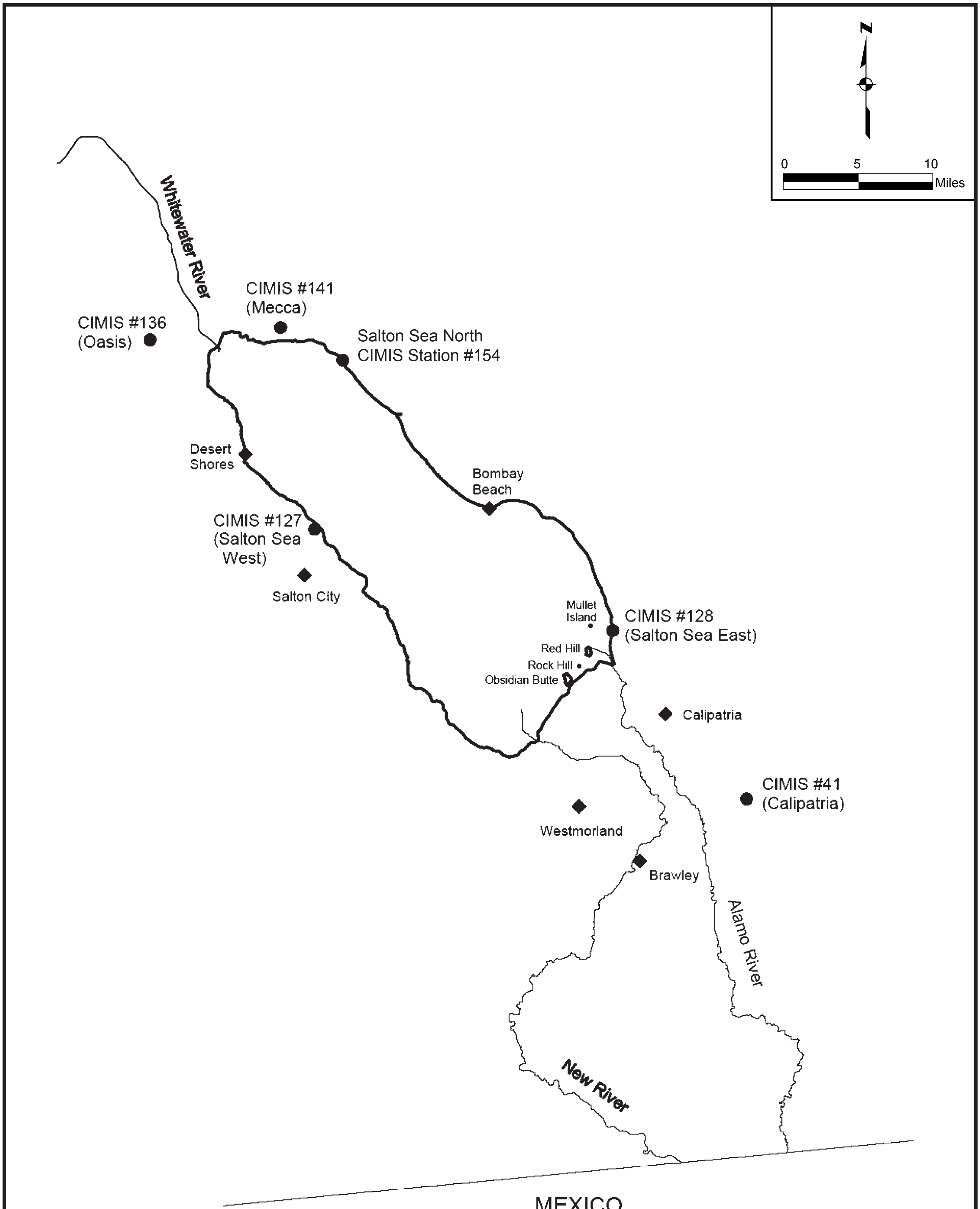
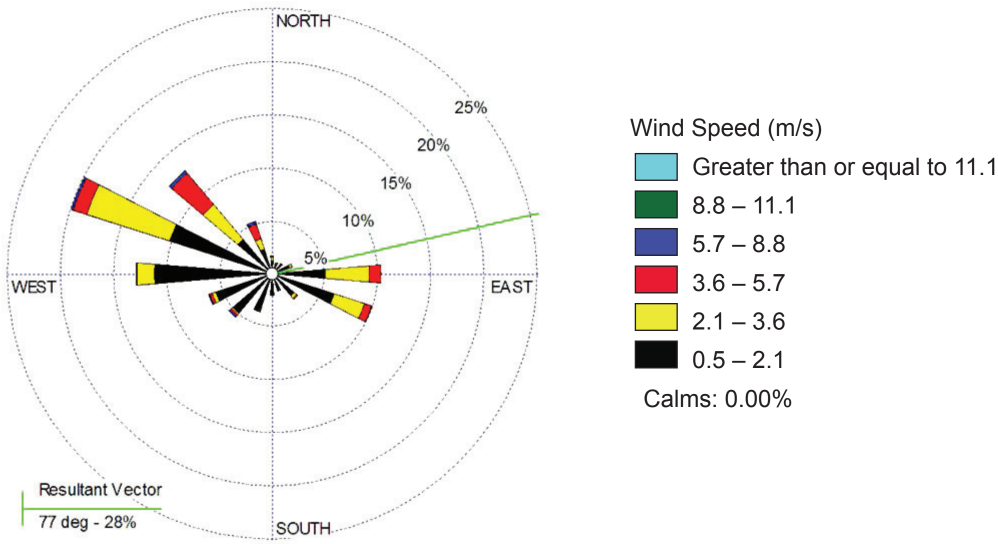


FIGURE D-2
LOCATION OF THE SALTON SEA CIMIS STATIONS

Note: Shoreline Elevation = 228 ft below msl
Adapted from Schladow, 2004.

CIMIS #136 (Oasis)



CIMIS #141 (Mecca)

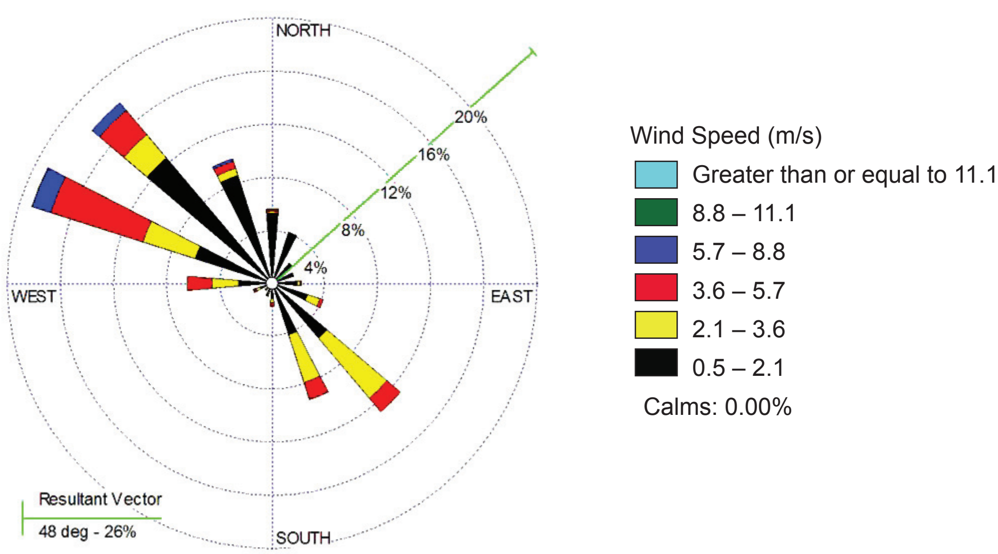
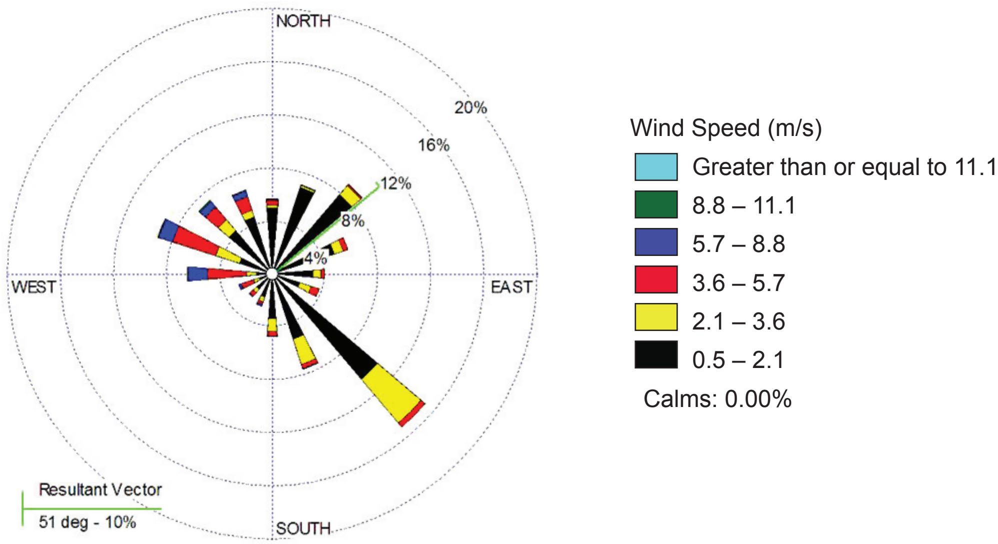


FIGURE D-3
WIND ROSE PLOTS FOR CIMIS STATIONS #136 (OASIS) AND #141 (MECCA)

CIMIS #154 (Salton Sea North)



CIMIS #127 (Salton Sea West)

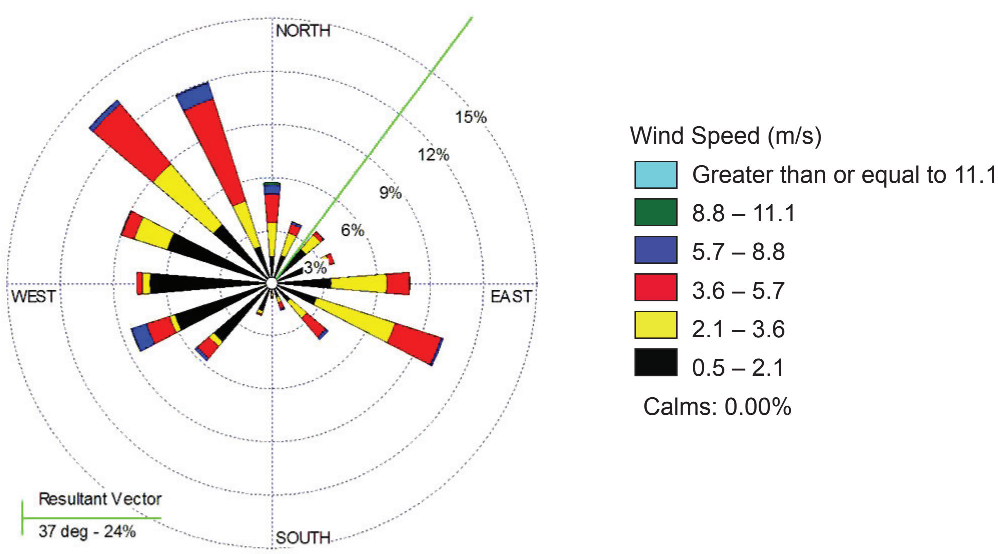


FIGURE D-4
WIND ROSE PLOTS FOR CIMIS STATIONS #154 (SALTON SEA NORTH) AND #127 (SALTON SEA WEST)

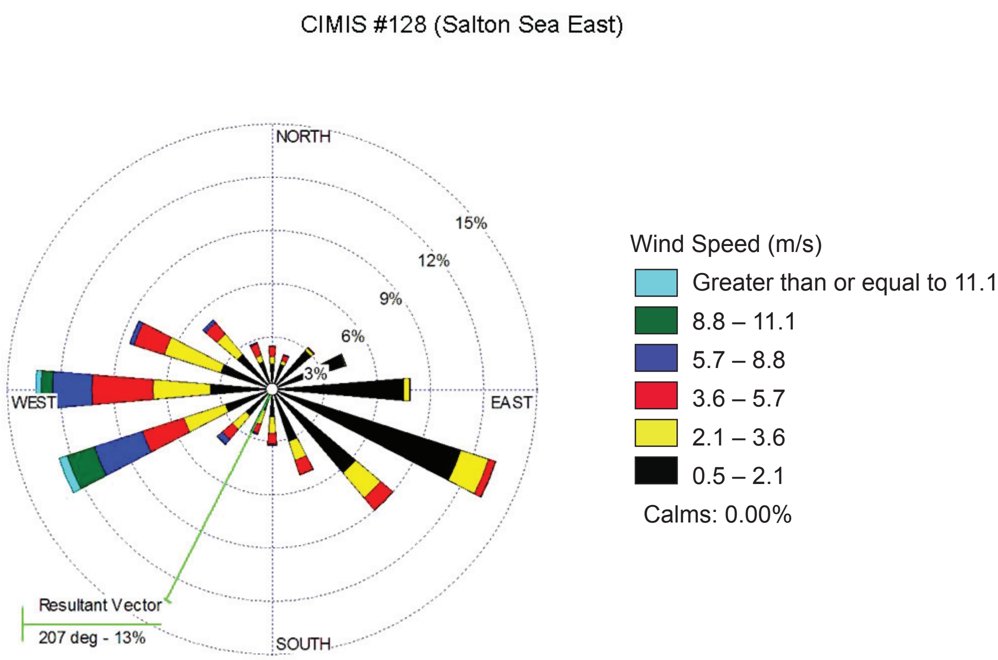


FIGURE D-5
WIND ROSE PLOT FOR CIMIS STATION #128 (SALTON SEA EAST)

particular directions are indicated by the length of the spokes on the wind rose. The magnitude of the winds is depicted by the colors with higher magnitudes represented by warmer colors. While the wind fields are complex at the Salton Sea, the highest winds are generally from the northwest in the north subbasin and from the west in the south subbasin. The maximum wind speeds are greater in the south subbasin. On-going wind field analysis is being performed by the U.S. Department of the Interior, Geological Survey (USGS) and may provide information for future multi-dimensional model refinements. For the purposes of one-dimensional modeling, an interpolated, inverse distance-weighted water surface area average wind field was derived from the CIMIS data for these five stations for each of the alternative geometries.

Other meteorological data, such as shortwave radiation, longwave radiation, air temperature, relative humidity, and precipitation do not vary considerably from station to station (Schladow, 2004). For the purposes of one-dimensional modeling, data from station #127 were utilized to represent these conditions at the Salton Sea.

Water Quality

Temperature

A chemical and physical limnological study of the Salton Sea was performed by Holdren and Montaño (2002) for the year 1999. The measurements included temperature at various depths for three sampling sites. Monthly measurements were taken from January through March, and October through December, and biweekly measurements were taken from April through September. The first site (SS-1) is located near the deepest point of the northern subbasin, the second site (SS-2) is in the middle between the subbasins, and the third site (SS-3) is located near the deepest point of the southern subbasin. Water surface temperatures ranged from a high of 36.5 degrees Celsius (˚C) (97.7 degrees Fahrenheit [˚F]) in August to a low of 14.2 ˚C (58.1 ˚F) in January.

Temperature contour plots generated from the Holdren and Montaño study data are presented in Figure D-6. The plots illustrate the typical thermal stratification pattern that is prevalent at the Salton Sea. In 1999, the Salton Sea was generally well mixed in the winter and spring, with extended stratification in the summer (June through September). It should be noted, however, that the Salton Sea is a polymictic lake, meaning that it may stratify and mix many times during the year.

Dissolved Oxygen

Dissolved oxygen is a particular concern at the Salton Sea because it is essential to survival of fish and other aquatic organisms. Surface water is often supersaturated with respect to dissolved oxygen for several months during daylight hours, while the bottom waters are virtually devoid of dissolved oxygen (Holdren and Montaño, 2002; Anderson and Amrhein, 2003). Dissolved oxygen supersaturation is caused by photosynthetic production of oxygen during the daytime. Holdren and Montaño (2002) have suggested that a concentration of 4.0 mg/L of dissolved oxygen is required for what are considered desirable aquatic species. However, species such as tilapia have been shown to be tolerant of infrequent very low dissolved oxygen concentrations (less than 2 mg/L) (FAO, 1986).

The thermally stratified period exhibits hypolimnetic anoxia and increasing concentrations of reduced compounds (hydrogen sulfide and ammonia), while the breakdown of the thermocline is generally associated with mixing the low oxygenated hypolimnetic water with surface water. The hydrogen sulfide and ammonia remove oxygen from the surface water through a process termed oxidation, resulting in low concentrations of dissolved oxygen throughout the water column. These periods of low dissolved oxygen are of particular concern, as fish and other aquatic organisms have little or no areas to retreat to find adequate dissolved oxygen. Events such as these have been correlated to some of the massive fish kills (Schladow, 2004).

Dissolved oxygen concentrations measured in Holdren and Montaño's limnological study of the Salton Sea (2002) ranged from greater than 200 percent saturation near the surface to zero in the bottom water. Holdren and Montaño (2002) reported that the period of severe oxygen depletion throughout the water column during August and September 1999 (0.21 mg/L on September 8, 1999) coincided with extensive fish kills. The dissolved oxygen concentrations from this study are presented in Figure D-7.

Transparency

Secchi disc depth is a common measurement of water transparency, or clarity, and represents the visible conditions of the lake. It is related to the absorption and scattering of light in water by various materials, including algae, suspended sediments, or other organic matter. Secchi disc depths were measured as part of the limnological study of Holdren and Montaño (2002). Euphotic depth, which is the depth to which only 1 percent of surface level light penetrates, was also measured. In many shallow lakes, euphotic depth is estimated as 1.7 times the Secchi depth (Scheffer, 1998 as cited in Holdren and Montaño, 2002). Secchi depths in the Salton Sea ranged from 0.4 to 1.4 meters (1.3 to 4.6 feet), but were generally around 1 meter (3.3 feet). Euphotic depths ranged from 1.8 to 4.8 meters (5.9 to 15.7 feet). Euphotic depth and Secchi depth were strongly correlated with a 4.2:1 ratio at all three sampling sites. These ratios are much higher than those of freshwater lakes (Holdren and Montaño, 2002).

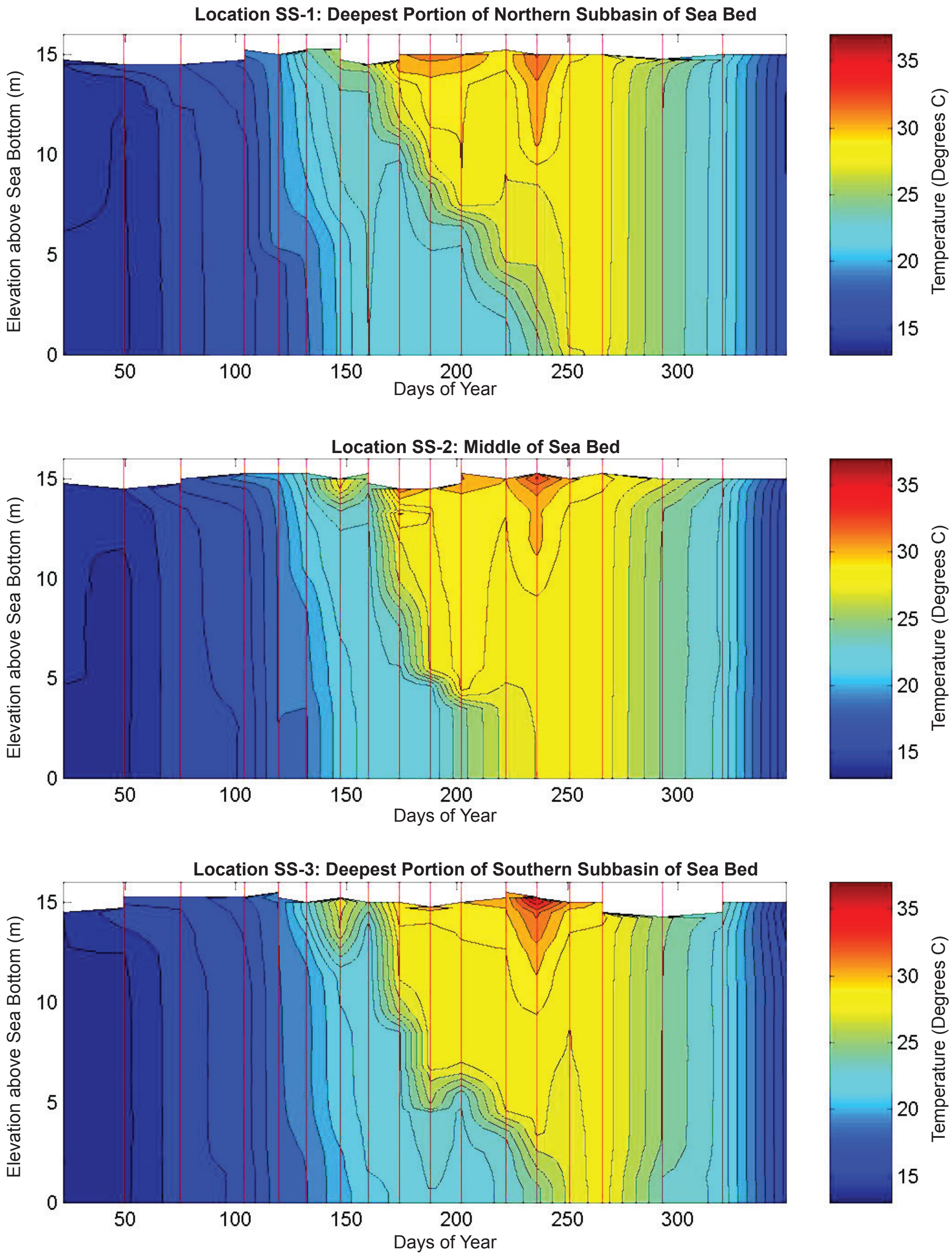
Phosphorus

Phosphorus is an essential nutrient for plant, including algal, growth, and is often the limiting factor for additional growth. Setmire et al. (2001) identified phosphorus as the limiting nutrient at the Salton Sea, and others (Holdren and Montaño, 2002; Schladow, 2004) have supported this conclusion. Phosphorus is present in water bodies in many forms, including dissolved and particulate organic phosphates from algae and other organisms, inorganic particulate phosphorus, polyphosphates, and dissolved orthophosphate. Dissolved orthophosphate is assimilated by phytoplankton and is, therefore, an important constituent to consider when assessing the productivity and quality of a water body. Total phosphorus is also measured in water quality studies, as it is an indication of the maximum level of productivity of a water body.

Holdren and Montaño's 1999 study measured both dissolved orthophosphate and total phosphorus in the Salton Sea. Dissolved orthophosphate was often below detection limits. Levels of dissolved orthophosphate were highest during the winter months and lowest during the spring and summer months, correlating with typical seasonal algal growth patterns. Total phosphorus concentrations were lowest in the fall and highest in the winter months, with peak concentrations between 50 and 200 micrograms/liter (µg/L) (0.05 and 0.2 mg/L) (Holdren and Montaño, 2002). Table D-1 presents the seasonal nutrient concentrations in the Salton Sea collected in 1999. Based on these data, an annual average total phosphorus concentration in the Salton Sea was calculated to be about 69 µg/L (0.069 mg/L). A draft Total Maximum Daily Load (TMDL) numeric annual average target for total phosphorus has been proposed for the Salton Sea by the Colorado River Basin Regional Water Quality Control Board (CRBRWQCB) at no greater than 35 µg/L (0.035 mg/L) (CRBRWQCB, 2005), as described in Chapter 6.

Nitrogen Concentrations

Nitrogen is present in water bodies in oxidized or reduced forms. Nitrate is commonly found in surface water. Ammonia is the form most readily utilized by phytoplankton, and is typically found in water with low oxygen concentrations. In their chemical analysis of the Salton Sea, Holdren and Montaño (2002) found that about 32 percent of the total nitrogen was ammonia, with higher concentrations near the bottom. The Salton Sea median ammonia concentration was about 1,180 µg/L and the daily maximum exceeded 2,400 µg/L (2.4 mg/L) at two locations. High levels of ammonia indicate frequent reducing conditions in the Salton Sea, and contribute to anoxia and fish toxicity. The annual mean concentration of nitrates and nitrites in the Salton Sea was 120 µg/L (0.12 mg/L). This is an order of magnitude lower than the concentration of nitrate/nitrite found in the tributaries to the Salton Sea.



Source: Holdren and Montano, 2002.

FIGURE D-6
CONTOURS OF OBSERVED TEMPERATURE FOR 1999

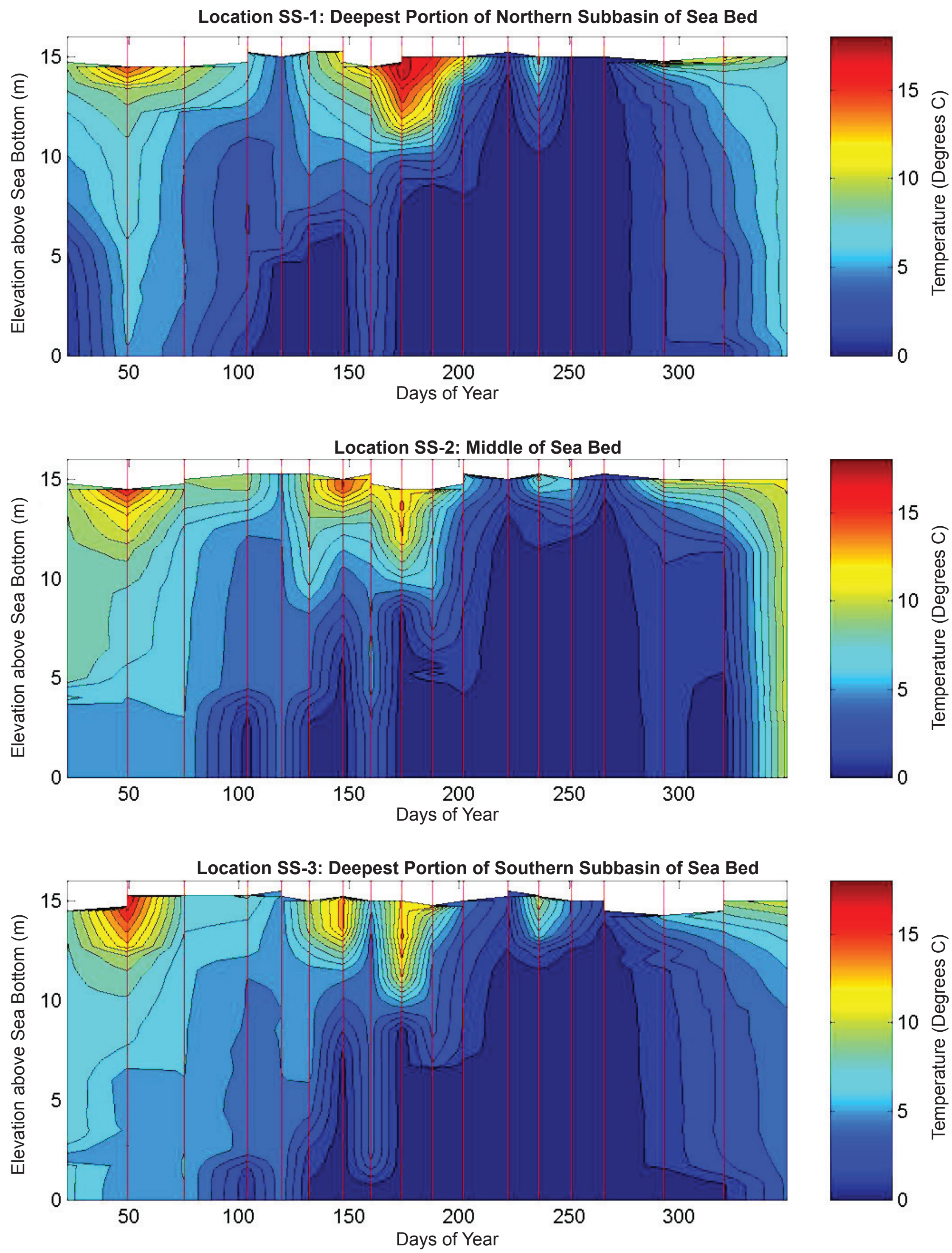


FIGURE D-7
CONTOURS OF OBSERVED DISSOLVED OXYGEN FOR 1999

Source: Holdren and Montano, 2002.

Table D-1
Seasonal Nutrient Concentrations in the Salton Sea and Tributaries

Constituent	Summer	Fall	Winter	Spring	Annual Mean[b]
Alamo River					
Soluble Orthophosphatea (mg/L)	0.23	0.456	0.492	0.454	0.408
Total Phosphorus (mg/L)	0.53	0.583	0.744	1.02	0.719
Nitrogen in the form of nitrate and nitrite (mg/L)	5	6.84	6.94	6.91	6.42
Nitrogen in the form of ammonia (mg/L)	0.89	0.629	1.57	1.97	1.26
Organic nitrogen and ammonia as measured by the Kjeldahl process (mg/L)	2.3	1.6	3.4	4	2.8
New River					
Soluble Orthophosphate[a] (mg/L)	0.548	0.928	0.773	0.537	0.697
Total Phosphorus (mg/L)	1.01	1.11	1.16	1.15	1.11
Nitrogen in the form of nitrate and nitrite (mg/L)	2.5	3.41	4.08	4.21	3.55
Nitrogen in the form of ammonia (mg/L)	3.84	3.36	3.55	2.74	3.14
Organic nitrogen and ammonia as measured by the Kjeldahl process (mg/L)	5.3	4.4	4.7	4.5	4.7
Whitewater River					
Soluble Orthophosphate[a] (mg/L)	0.632	0.709	0.823	0.675	0.71
Total Phosphorus (mg/L)	0.753	0.92	0.899	0.889	0.865
Nitrogen in the form of nitrate and nitrite (mg/L)	15.8	15.4	12.2	13.9	14.3
Nitrogen in the form of ammonia (mg/L)	0.45	0.396	1.52	0.551	0.729
Organic nitrogen and ammonia as measured by the Kjeldahl process (mg/L)	1.8	1.5	3.1	1.7	2
Salton Sea					
Soluble Orthophosphate[a] (mg/L)	0.01	0.02	0.042	0.011	0.021
Total Phosphorus (mg/L)	0.053	0.026	0.107	0.088	0.069
Nitrogen in the form of nitrate and nitrite (mg/L)	0.1	0.05	0.19	0.16	0.12
Nitrogen in the form of ammonia (mg/L)	1.45	1.27	1.17	0.76	1.16
Organic nitrogen and ammonia as measured by the Kjeldahl process (mg/L)	4.1	4.1	2.3	3.6	3.5

Source: Holdren and Montaño, 2002

[a] Soluble orthophosphate is the dissolved portion of phosphorus in a phosphate form

[b] The Annual Mean value is the title in the table as reported by Holdren and Montaño. This value actually is the mean of the seasonal concentrations. The analysis included a higher number of data points in the summer months. Therefore, an actual mean of the data would provide more weight to the summer months than if the number of data points were consistent for all seasons. The last column is actually a four seasonal mean value.

Nitrogen to Phosphorus Ratios

The ratio of nitrogen to phosphorus (N:P) is often used to indicate which nutrient is limiting plant growth. Since healthy algal cells in saltwater require about a 7:1 ratio (Reynolds, 1986), any body of water with a higher ratio is considered phosphorus limited, while a body of water with a lower ratio is considered nitrogen limited. The Salton Sea exhibited very high N:P ratios in 1999: 194:1 for total nitrogen to total phosphorus and 228:1 for total inorganic nitrogen to soluble orthophosphate (Holdren and Montaño, 2002). These results strongly suggest that phosphorus is the limiting nutrient in the Salton Sea (Setmire et al., 2001).

Chlorophyll Concentrations

Chlorophyll *a* is used as a measure of algal biomass in a water body. Chlorophyll *a* data were collected by San Diego State University (SDSU) from the Salton Sea in 1999 (Tiffany et al., 2001). Due to the limited data availability, a long term trend in algal growth cannot be found from these data. However, chlorophyll *a* concentrations from the SDSU study ranged from greater than 100 μg/L in summer at the surface to less than 10 μg/L at mid-depth in the fall. The measurements were taken at 0, 3, and 6 meters (0, 9.8, and 19.7 feet) from the water surface and are shown in Figure D-8. Concentrations were highest in March and July-August, and are likely indicative of algal blooms (Schladow, 2004).

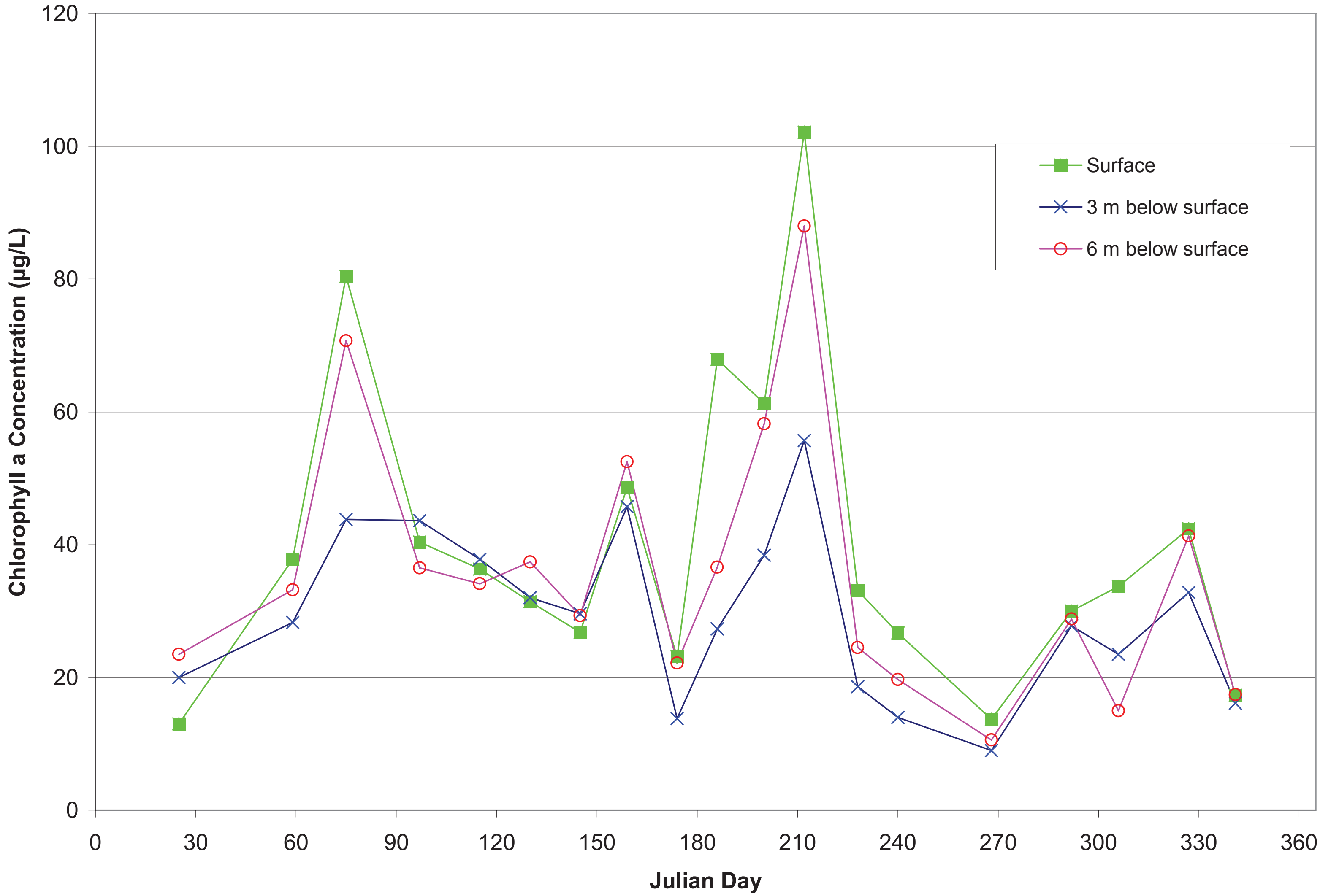
Trophic State

The trophic state of a lake is a concept used to describe the general biological productivity and evolution of a lake. The Trophic State Index (TSI) developed by Carlson (1977) is a unitless index that has been widely used to categorize lakes based on chlorophyll *a* concentration, Secchi depth, and total phosphorus concentration. Lakes with TSI values less than 40 are classified as *oligotrophic*, between 40 to 50 as *mesotrophic*, between 50 to 60 as *eutrophic*, and greater than 70 as *hypereutrophic*. The TSI provides a relative marker for the trophic state. TSIs of 60 and 62 were calculated from data collected from May through September in 1999, which classify the Salton Sea as eutrophic (Holdren and Montaño, 2002). Additional data produce a TSI of 64 to 65 (CRBRWQCB, 2005), which indicates that the Sea is hypereutrophic.

Sources of Nutrient Loading to the Salton Sea

The eutrophic conditions at the Salton Sea are largely controlled by the biologically essential nutrients supplied to the water body. The Salton Sea has been shown to be controlled, or limited, by available phosphorus. Nutrients are supplied to the Salton Sea from both external and internal sources. The external sources of nutrients are from rivers and drains. Internal sources, also known as loadings, serves as a nutrient source through sediment release and resuspension.

Holdren and Montaño (2002) reported external nutrient concentrations in 1999. This information was analyzed through a linear-interpolation process used in the water quality model, and the result was multiplied by daily flows for each river to develop the loads summarized in Table D-2. This effort was completed as part of the boundary conditions used in the water quality model used to analyze the PEIR alternatives.



Source: Tiffany et al., 2001

FIGURE D-8
MEASURED CHLOROPHYLL *A* CONCENTRATION IN THE SALTON SEA DURING 1999

Table D-2
External Nutrient Loading to the Salton Sea in 1999

Water Body	Phosphorus	Orthophosphate	Ammonia	Nitrate and Nitrite
New River	671,000	411,000	2,236,000	2,160,000
Alamo River	565,000	312,000	970,000	4,874,000
Whitewater River	57,000	46,000	46,000	934,000
Direct Drains	137,000	77,000	237,000	1,216,000
Total	1,430,000	846,000	3,490,000	9,186,000

Notes:
All values in kilograms/year
Loads developed from source concentrations from Holdren and Montaño (2002) and historic flows, as summarized in Appendix H-2.

Rivers and Drains

The principal external sources of nutrients are the New, Alamo, and Whitewater rivers, and agricultural drains. A consistent, long term study of the nutrient loading into the Salton Sea does not exist. Setmire et al. (2001) compared the results of the Federal Water Quality Administration (1970) study of nutrient loading in 1968 and 1969 to the results from Holdren and Montaño's (2002) measurements of phosphorus and nitrogen concentrations in the three tributary rivers for 1999. Overall, nutrient concentrations and loads had increased significantly over the 30-year period. Phosphorus concentrations and loads nearly doubled between 1969 and 1999, while nitrogen has increased by an estimated 70 to 140 percent during this period. Recent data, suggest that the phosphorus concentrations in the rivers may no longer be increasing (Holdren, 2005).

For this study, the total phosphorus and orthophosphate concentration data from Holdren and Montaño (2002), as shown in Figure D-9, were incorporated as inputs to the water quality model. The total phosphorus load from the rivers is estimated by multiplying daily discharge for each river by the linearly-interpolated source phosphorus concentration. Total phosphorus load to the Salton Sea from all rivers and drains was estimated at about 1.4 x 10^6 kilogram/year (1.6 x 10^3 pounds/year).

The ammonia and nitrate plus nitrite concentrations from Holdren and Montaño (2002), as shown in Figure D-10, were also incorporated as inputs to the water quality model. The total nitrogen load to the Salton Sea from all rivers and drains was estimated at about 12.7 x 10^6 kilogram/year (14,000 tons/year).

Atmospheric Deposition

Atmospheric deposition of phosphorus occurs when particulates containing the nutrient are captured by falling precipitation. Though not a significant source of phosphorus, Anderson and Amrhein (2002) estimated that 0.006 x 10^6 kilogram (6.5 tons) are deposited on the Salton Sea each year, using default values from Walker (1995). Atmospheric deposition of nitrogen on the Salton Sea was also estimated by Anderson and Amrhein (2002) from data collected by the National Atmospheric Deposition Program for the year 1999. They estimate that 0.17 x 10^6 kilogram/year (185 tons/year) of nitrogen are deposited on the water surface. Atmospheric deposition was considered negligible for the water quality modeling analysis in this study of the Salton Sea and was not included in the model.

Sediment Release

The release of phosphorus from the sediment pore water was quantified by Anderson and Amrhein (2002) through two separate methods: core flux measurements in the laboratory and measurements from devices deployed in the Salton Sea sediments. Core flux experiments involved obtaining sediment samples from the Salton Sea, preserving the samples, and transporting the samples to the laboratory for measurement of loading rates for a series of constituents. The second method involved the use of “peepers,” which are compartmentalized polyvinyl chloride devices deployed into the sediment and left to equilibrate to pore water concentrations at various depths. Measurements are then taken of pore water concentration in different chambers of the apparatus and flux estimates are calculated from the vertical gradients in measured concentrations.

Andersen and Amrhein (2002) found that the flux rates calculated from the peepers (1.2 ± 0.9 milligrams/meter squared/day) were significantly lower than the results of the core flux experiments (5.5 ± 1.6 milligrams/meter squared/day). The core flux measurements varied with season due to temperature dependence. Results from Andersen and Amrhein (2002) show that the phosphorus sedimentation rates are greater than the release rates.

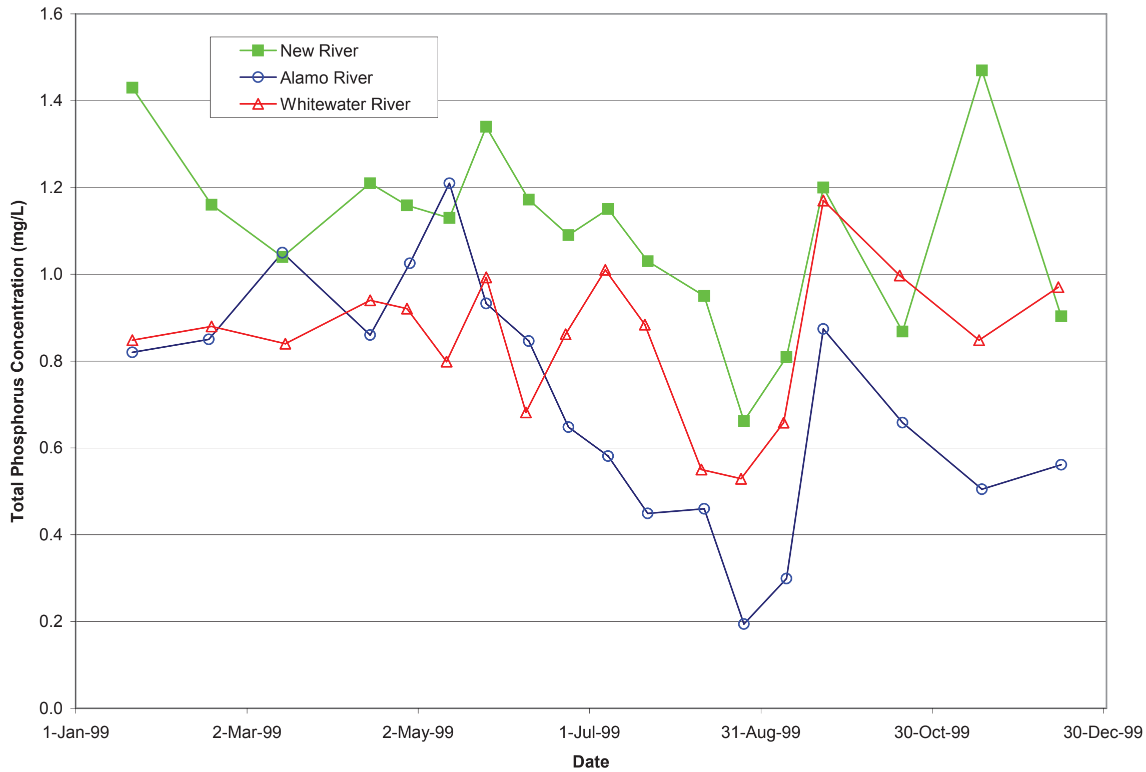
Due to difficulties in deployment and retrieval of peepers, Anderson and Amrhein gave more credibility to the core flux-derived rates. They estimated the annual phosphorus load to the Salton Sea from sediment release to be about equivalent to that from external sources (Anderson and Amrhein, 2002). For the water quality calibration effort discussed below, results from Anderson and Amrhein’s core flux experiments were used to guide the specification of the temperature-dependent release rate of orthophosphate from the sediments in the model.

The sediment release rate of ammonia through the dispersion of pore water to the overlying water column reported by Anderson and Amrhein (2002) averaged 77.1 ± 19.7 milligrams/meter squared/day for the core flux experiments and 23.4 ± 18.9 milligrams/meter squared/day for the peeper experiments. The water quality modeling calibration effort discussed below initially attempted to use the core-flux rates, but during calibration it was found that these rates significantly over-predicted ammonia concentrations in the Salton Sea. Ammonia flux rates more similar to those derived from the peepers were eventually used for the modeling effort.

Resuspension

Resuspension is another mechanism of phosphorus loading to the Salton Sea in addition to the passive diffusion from sediment pore water to the water column. The physical wind-induced resuspension of bottom sediments delivers both particulate organic phosphorus and dissolved orthophosphate to the water column. The importance of sediment resuspension to water column orthophosphate and subsequent algal growth was identified by Schladow (2004). Anderson and Amrhein (2002), in evaluating the rates of sedimentation, noted the effects of resuspension at shallow water sites. One such site yielded sedimentation rates 15 times higher than that of sedimentation rates in deep water sites. In the water quality modeling in this study, a user defined pore water concentration of orthophosphate is used with a wind power law relationship to resuspend bottom sediments and pore water during high wind events. The pore water orthophosphate concentrations used in the calibration effort were taken from pore water measurements reported by Anderson and Amrhein (2002). Final model simulations used a pore water orthophosphate concentration of 1.0 mg/L which is consistent with that found from Anderson and Amrhein’s peeper measurements.

Resuspension of bottom sediments also delivers ammonia to the water column during periods of high wind events. The resuspension of ammonia is treated in the same fashion as orthophosphate in the water quality modeling. A pore water ammonia concentration of 8 mg/L was incorporated from measurements by Anderson and Amrhein (2002). This value is on the low side of measurements taken by Anderson and Amrhein (2002), but use of higher values during calibration significantly over-predicted ammonia concentrations in the Sea.



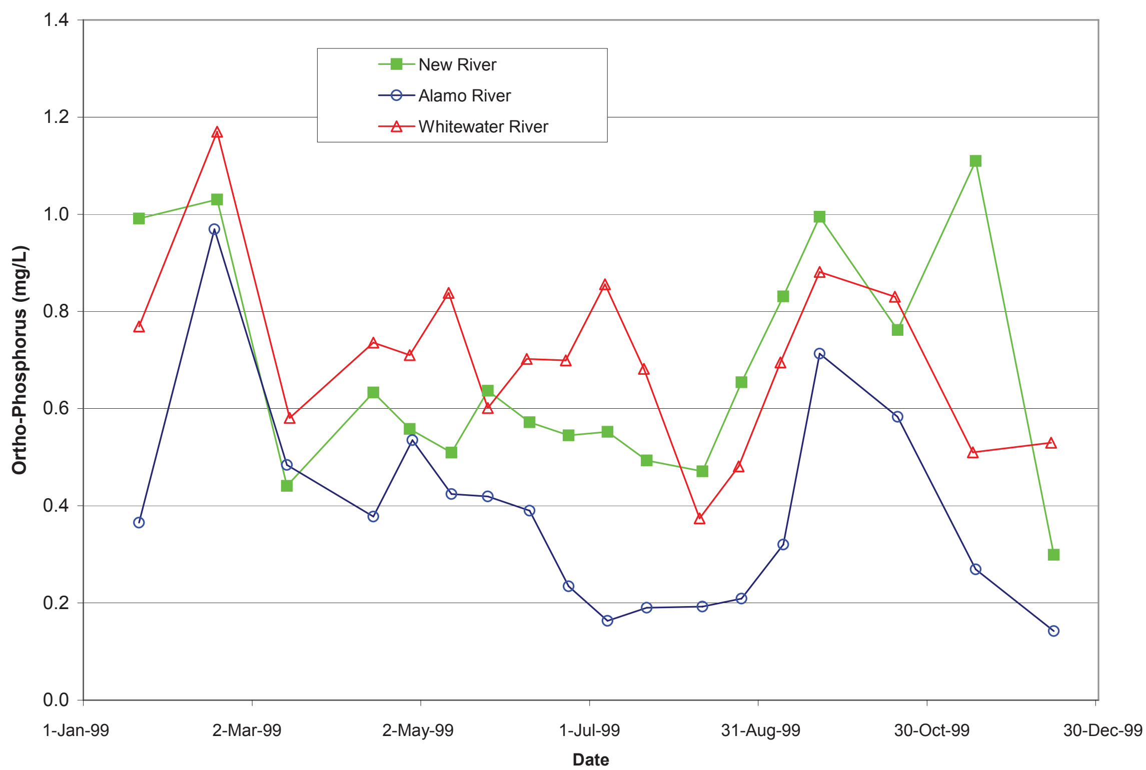
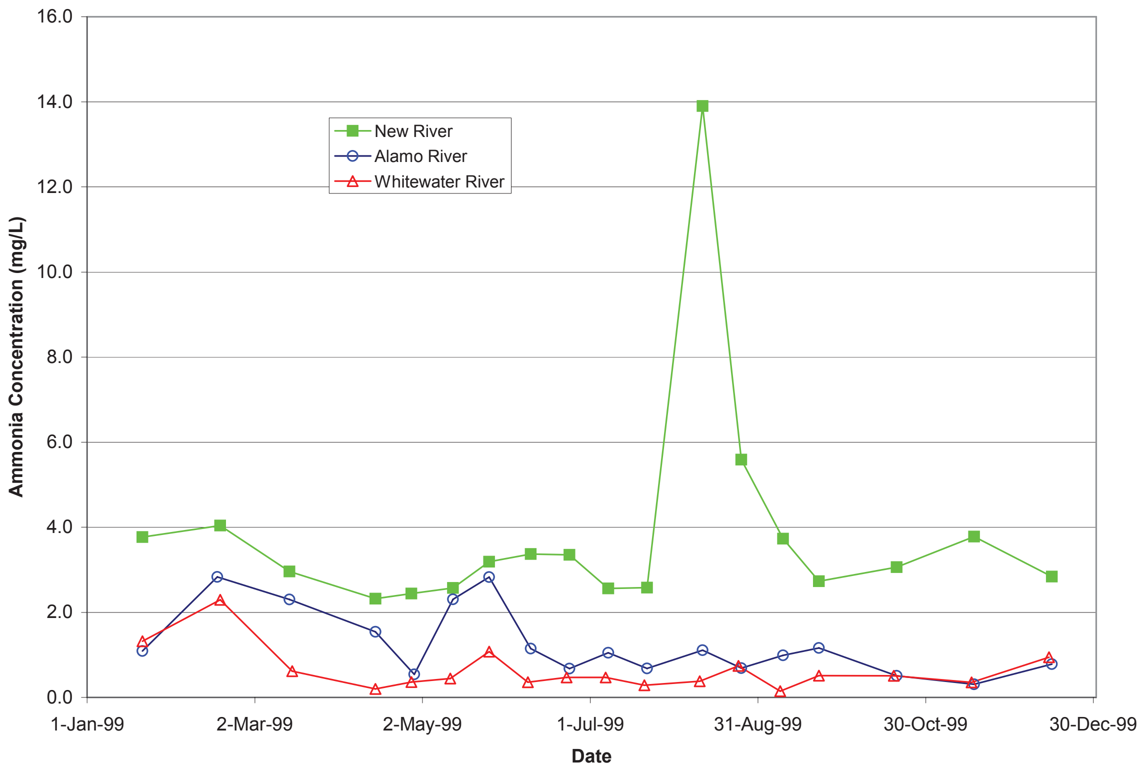
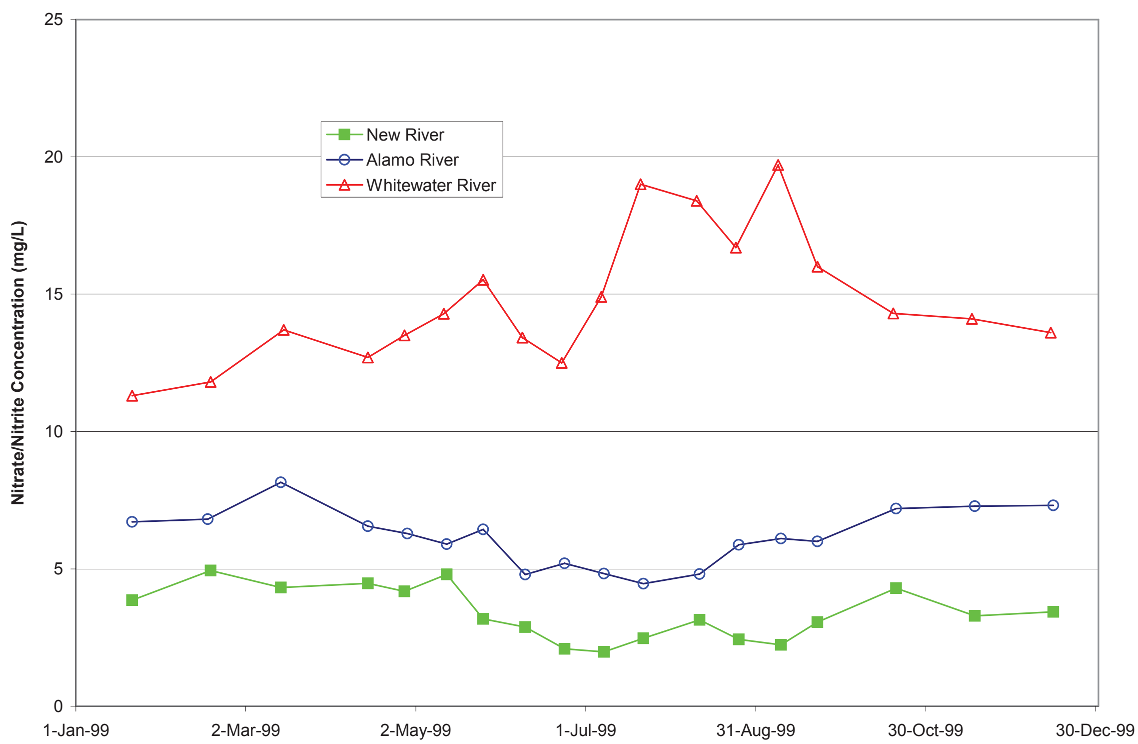


FIGURE D-9
TOTAL PHOSPHORUS AND ORTHOPHOSPHATE CONCENTRATIONS IN THE RIVERS

Source: Holdren and Montaño, 2002





Source: Holdren and Montaño, 2002

FIGURE D-10
AMMONIA AND NITRATE/NITRITE CONCENTRATIONS IN THE RIVERS

Nutrient Sinks in the Salton Sea

The nutrients entering the Salton Sea undergo a complex set of reactions. Certain reactions effectively remove the nutrients from the Salton Sea by either physical removal (generally volatilization) or rendering them unavailable for uptake by algal communities (usually by burial). The sinks of phosphorus, nitrogen, and sulfide are discussed below. Mechanisms removing nutrients from the water column to the sediment are also listed as mechanisms of removal, even though the material deposited in the sediment may re-enter the sea through either pore water diffusion or resuspension.

Phosphorus

Phosphorus is removed from the water column through the following mechanisms:

- Settling of particulate phosphorus;
- Co-precipitation of dissolved orthophosphate to particulate phosphate, which is then lost by settling;
- Adsorption of dissolved orthophosphate to particulate phosphate, which is then lost by settling;
- Settling of phytoplankton, which contain phosphorus; and
- Permanent removal of phosphorus in the form of dead biomass (i.e. burial of settled algae and sequestration in the form of fish bones and shells).

Nitrogen

Nitrogen is removed from the water column through the following mechanisms:

- Conversion to nitrogen gas and subsequent volatilization;
- Volatilization of ammonia;
- Settling of phytoplankton, which contain nitrogen; and
- Settling of organic nitrogen.

Sulfide

Hydrogen sulfide produced in the Salton Sea is removed by one of the following three mechanisms:

- Volatilization of hydrogen sulfide to the atmosphere from surface waters;
- Oxidation of hydrogen sulfide to sulfate; and
- Complexation of hydrogen sulfide to other constituents which settle.

PROCESSES GOVERNING PHOSPHORUS DYNAMICS

Phosphorus loads to the Salton Sea contribute to the high level of productivity. Previous studies, while agreeing on the importance of phosphorus to the eutrophic state of the Salton Sea, differ in their view of the importance of internal loading sources and processes controlling water column phosphorus concentrations. This section provides a brief summary of the differing scientific opinions and depicts the degree of uncertainty in quantifying phosphorus dynamics.

Holdren and Montaño (2002) provide the most comprehensive water quality data set for the Salton Sea. The external nutrient loads for 1999 used by most investigators are developed from these source water concentration measurements and are thus similar. Anderson and Amrhein (2002), however, have suggested that significant internal release of phosphorus as a diffusive flux from sediments is occurring. Based on sediment core experiments and pore water sampling, they contend that sediment release of phosphorus may be similar in magnitude to that of external loads. Schladow (2004) has suggested that the presence of lower total and dissolved phosphorus concentrations near the bottom of the Salton Sea during stratified periods suggest that there is little or no net internal loading of phosphorus from the deep sediments. Rather, he suggests that wind-induced resuspension of sediments provides a significant mechanism to bring phosphorus into the water column in addition to the external loads.

Past studies (Setmire et al., 2001; Holdren and Montaño, 2002; Schladow, 2004) have indicated that the phosphorus concentrations in the Salton Sea were lower than what would be expected given the external loading rates. Total phosphorus loadings to the Salton Sea have doubled over the past 30 years, but total phosphorus concentrations in the Salton Sea are largely unchanged. There appears to be a significant process controlling the phosphorus concentrations in the water column. Both the internal load mechanisms, either sediment release and sediment resuspension, should not be viewed to suggest net internal loads. Anderson and Amrhein (2002) suggest that the effect of sediment release when combined with sedimentation results in a net loss of phosphorus from the water column. Holdren and Montaño (2002) and Anderson and Amrhein (2002) indicate that removal of phosphorus from the system may be occurring through precipitation as hydroxyapatite (or other apatite minerals), either directly or through co-precipitation/sorption with calcite, and through incorporation into fish bones and shells of aquatic invertebrates.

It appears possible that both the diffusive flux from the sediments and the wind-induced resuspension of sediments are providing phosphorus to the water column. The water quality modeling discussed in the next section incorporates both of these internal mechanisms into the formulation and calibration.

MODELING METHODOLOGY AND ASSUMPTIONS

Purpose and Methodology

The potential for increased stratification, combined with continual production of hydrogen sulfide and ammonia from decomposition of organic materials and release from the sediments, could have significant impacts on future water quality, aquatic organisms, and restoration effectiveness. While this concern appears plausible with the current understanding of the thermal structure of the Salton Sea, nutrient cycling, and measured water quality data, little quantitative analysis has been performed to couple hydrodynamics and water quality for the Salton Sea and the alternative configurations. Considerable limitations exist, both in terms of useful data and in understanding the biological and chemical processes at the Salton Sea. The purpose of this water quality modeling effort is to simulate, within the limits of the data, tools, and current understanding of the mechanisms, the relative effects of the alternatives on water quality and thermal regime. This study should not be interpreted as providing *absolute* predictions of the future Salton Sea conditions, but rather as indicating where water quality problems are likely to be of concern, and provides information on the *relative comparison* of various alternatives, and identifies areas in need of future study and data collection.

The understanding of two processes is critical toward assessing current and future water quality conditions at the Salton Sea. First, the thermal structure of the Salton Sea plays a dominant role in the vertical mixing and associated exchange of hypolimnetic water (often anoxic) with epilimnetic water (usually oxic). Frequent and deep vertical mixing, characterized by a relatively homogeneous temperature profile, allows dissolved oxygen to penetrate the water column and prevents prolonged periods of anoxia at the sediment-water interface. Conversely, a stratified Salton Sea could allow for prolonged periods of hypolimnetic anoxia, and high hydrogen sulfide and ammonia concentrations which, upon mixing, could deplete the water column of dissolved oxygen. Second, the nutrient dynamics of the Salton Sea control the productivity and eutrophic conditions, and are influenced by thermal structure and sediment conditions.

In order to better understand the thermal regime at the Salton Sea, two distinctly different numerical models were calibrated and applied. The one-dimensional Dynamic Lake Model-Water Quality (DLM-WQ) model had previously been applied to the Salton Sea and was shown to provide a reasonable simulation of the thermal structure for 1999 conditions (Schladow, 2004). In order to determine whether the one-dimensional assumption of the DLM-WQ model was a significant limitation for addressing future conditions at the Salton Sea, the three-dimensional hydrodynamic model, SI3D, was applied for identical conditions. The SI3D model, originally developed by the USGS (Smith and Larock, 1997), has been adapted for lakes by the University of California, Davis (UC Davis), and demonstrated to work well for large, shallow lakes, such as Clear Lake, California (Rueda and Schladow, 2003). The DLM-WQ model results were validated through a separate, independent SI3D model simulation. Then, the DLM-WQ model was applied to analyze nutrient conditions at the Salton Sea.

The DLM-WQ model was calibrated and applied for 1999 conditions. The year 1999 was selected for calibration due to the relatively complete data set, including temperature and dissolved oxygen profiles, provided by Holdren and Montaño (2002). A detailed discussion of the model calibration and application to restoration alternatives is presented in following sections of this appendix.

Model and Data Limitations

The DLM-WQ model is a one-dimensional hydrodynamic model that simulates the vertical distribution of temperature, salinity, and density in small- to medium-sized lakes and reservoirs. It is based on earlier versions of the widely used DYRESM reservoir model developed by the Centre for Water Research at the University of Western Australia. The assumption of one dimensionality means that variations in density, temperature, and water quality parameters in the lateral direction are assumed to be small when compared with variations in the vertical directions. UC Davis adapted the model to couple the temperature and mixing process with a set of biological and chemical processes that describe phytoplankton growth, the cycling of nutrients, dissolved oxygen, and the fate of particulate material. As part of the PEIR, an approximate hydrogen sulfide algorithm was developed and implemented in the DLM-WQ model. Diagrams that demonstrate the phosphorus, nitrogen, and hydrogen sulfide process, as represented in the DLM-WQ model, are presented in Figures D-11, D-12, and D-13. As stated previously, the hydrogen sulfide processes considered in this version of the model are very approximate and were developed to only capture the major aggregate pathways.

Preliminary comparisons of the one- and three-dimensional models indicate that the DLM-WQ and SI3D model simulations produce similar trends in thermal stratification, as shown in Figure D-14. The similar trends include both development of the thermocline and mixing, with the water in the SI3D model accumulating slightly more heat than the water in the DLM-WQ model. The similarity of the model results under the same forcings (meteorological conditions) indicates that the one-dimensional assumption of DLM-WQ is not a significant limitation. Further comparative simulations with the SI3D model and a companion report are being prepared by UC Davis, but were not available during the preparation of the PEIR.

In general, numerical analytical tools are only as useful as the data from which the models are constructed and can be compared. A traditional calibration and validation procedure was not possible in this study due to the limited available data sets. Only a single recent year (1999) exists for which comprehensive field measurements are available and can be used to support water quality modeling. While the calibration results are rather good, the model could not be verified through an independent time period simulation.

The DLM-WQ model considers the transfer of nutrients from the water column to the sediment layer, as well as the release of nutrients from the sediment layer to the water column. While the individual processes of sediment release, resuspension, and sedimentation are considered, a limitation exists with the model in that these two sediment pools, one which releases nutrients to the water column and the other that serves as a sink for nutrients, are not coupled in the model. Therefore, the model assumes an unlimited supply of nutrients in the sediments available for release into the water column. This limitation was partially overcome through manual adjustments to the sediment-water processes, as described in the following sections.

The application of the DLM-WQ model to excessively high salinities or extremely shallow water depths should be carefully interpreted as the model algorithms are designed for salinities less than 45,000 mg/L and the model layer structure may not be sufficient for shallow depths.

The water quality characteristics of the Saline Habitat Complex cells were also described using the EUTROMOD model (Reckhow, 1996), which includes a large, comparative lake and pond database for North America. The empirical model consists of a series of regression relationships that use influent nutrient chemistry, hydraulic retention time, and average lake depth to predict average summer water quality conditions such as chlorophyll *a* concentrations, in-lake phosphorus and nitrogen concentrations, water clarity, and lake TSI. The TSI is a single number that incorporates various water quality values on a scale from 1 to 100, where higher values indicate more enriched, eutrophic conditions.

DLM-WQ MODEL CALIBRATION

The DLM-WQ model was calibrated to 1999 conditions, as described above, with the following parameters:

- Temperature
- Dissolved oxygen
- Chlorophyll *a*
- Orthophosphate
- Ammonia
- Nitrates

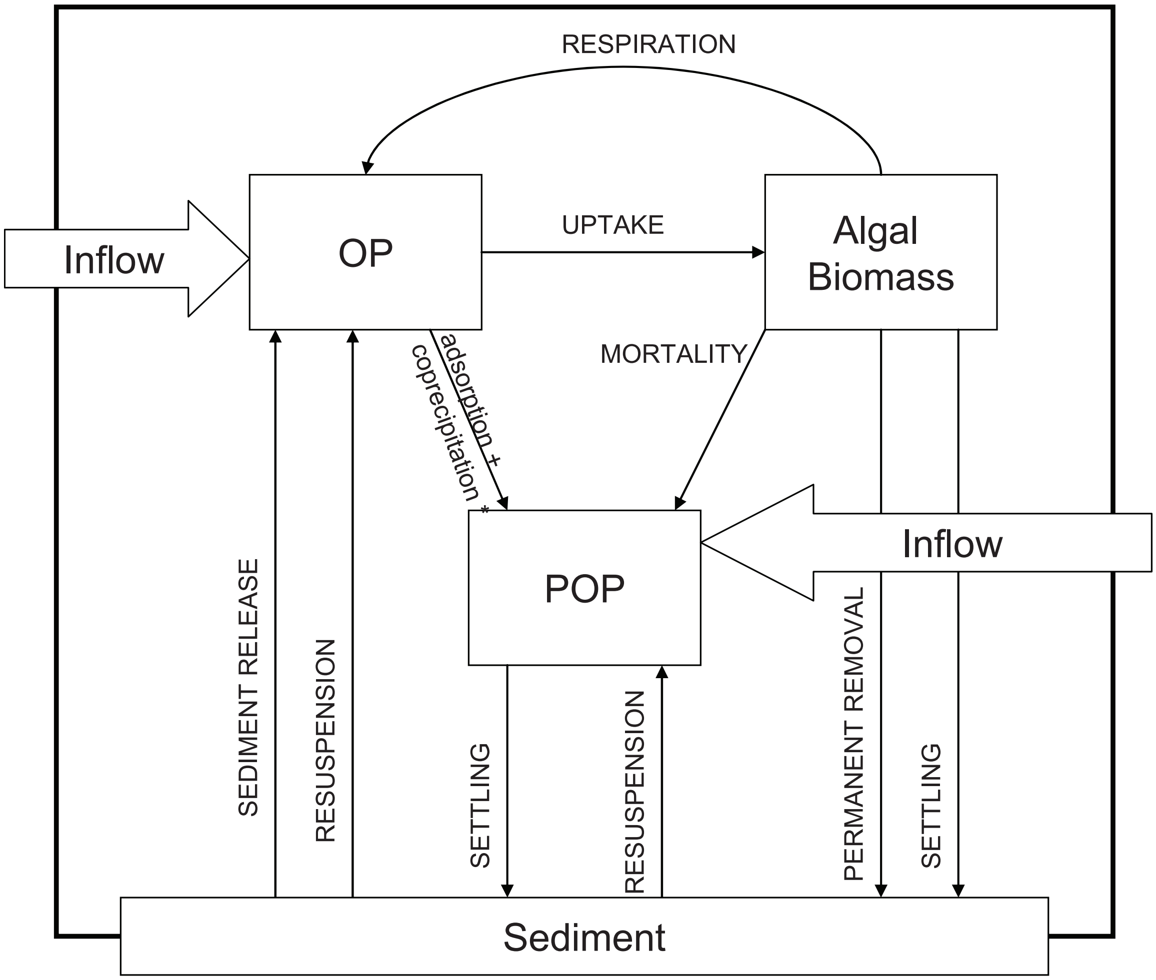
The calibration data set included 17 vertical profiles for temperature and dissolved oxygen spaced throughout the year (Holdren and Montaño, 2002). Grab sample data reflecting near surface and near bottom conditions were available for chlorophyll *a*, orthophosphate, total phosphorus, ammonia, and nitrates (Tiffany et al, 2001; Holdren and Montaño, 2002).

Temperature was calibrated first, primarily though an adjustment of a scaling factor applied to measured winds. This approach assumes that the measured wind data (measured over land) need to be scaled up to reflect the wind velocity over water. Subsequent to the temperature calibration, the other parameters were calibrated as a group considering the strong interaction between such water quality parameters as chlorophyll *a*, dissolved oxygen, and nutrient concentrations. Calibration of specific components is explained further below.

Data Sources

Observed Water Quality

Water quality conditions of the Salton Sea for 1999 are described by the Holdren and Montaño (2002) data set, including temperature, dissolved oxygen, lab calculated TDSs (used to estimate salinity), dissolved orthophosphate, total phosphorus, ammonia, and nitrate/nitrite. The same data set was used to describe the inflow water quality for New, Alamo, and Whitewater rivers, and a combined flow term for direct drains and tributaries, including Salt and San Felipe creeks. River water temperatures were interpolated to a daily time scale based on daily air temperature data (Chung, 2005). Alamo River water quality and temperature were applied to the combined flow term because Setmire et al. (2001) indicated that this is a good approximation of water quality in the direct drains. Groundwater contribution is small and is considered negligible for this study.



Note: OP is orthophosphate and POP is particulate organic phosphorus.

FIGURE D-11
PHOSPHORUS PROCESSES REPRESENTED IN THE DLM-WQ MODEL

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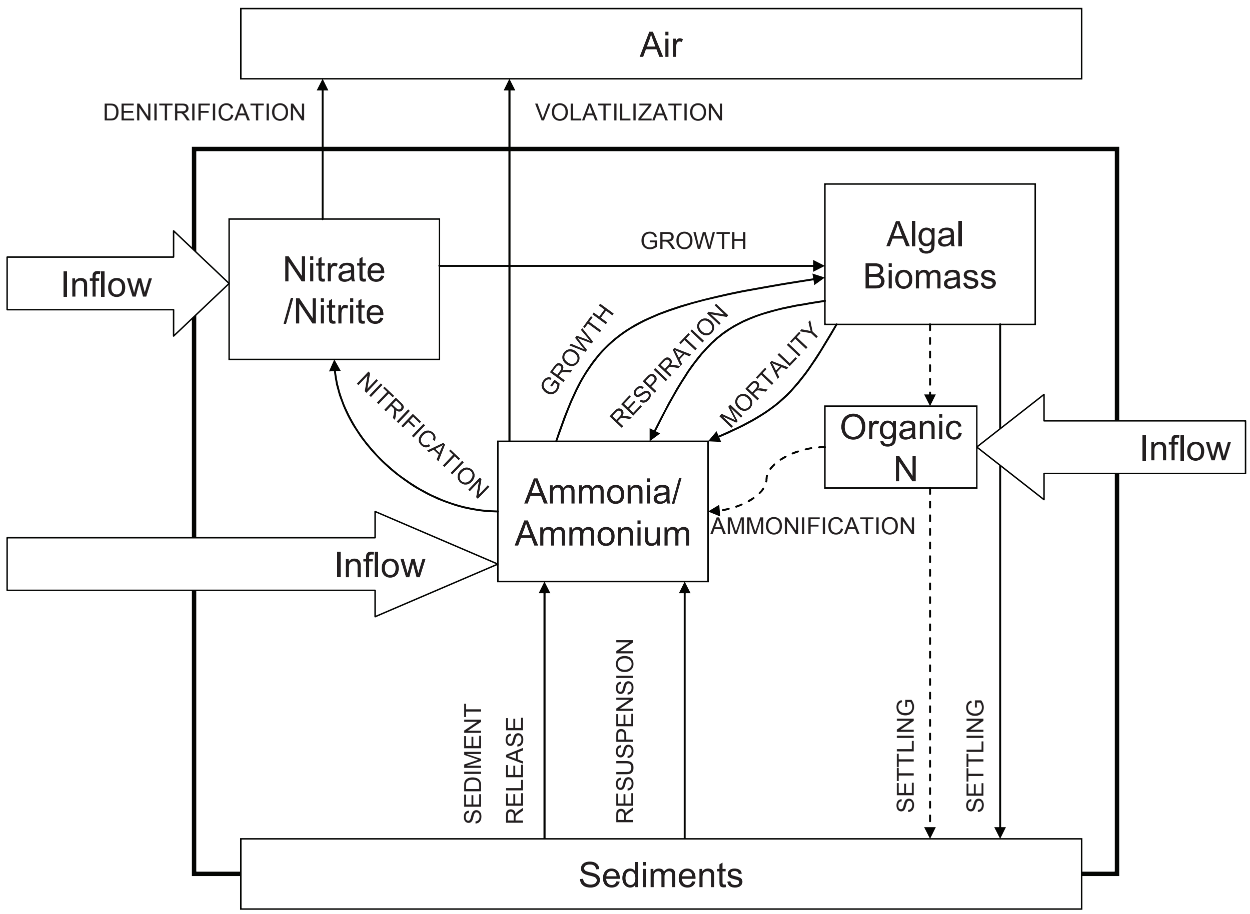

FIGURE D-12
NITROGEN PROCESSES REPRESENTED IN THE DLM-WQ MODEL

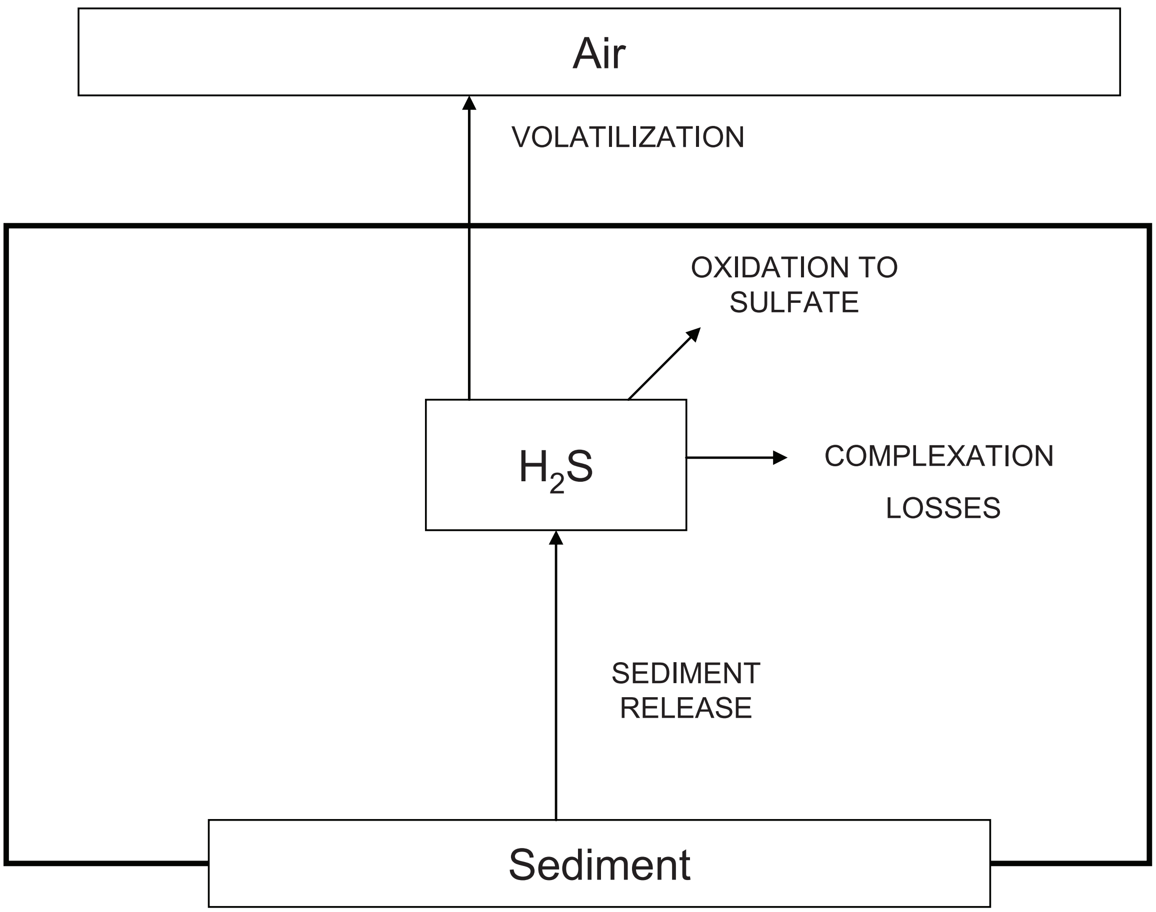

FIGURE D-13
SIMPLIFIED HYDROGEN SULFIDE PROCESSES REPRESENTED IN THE DLM-WQ MODEL

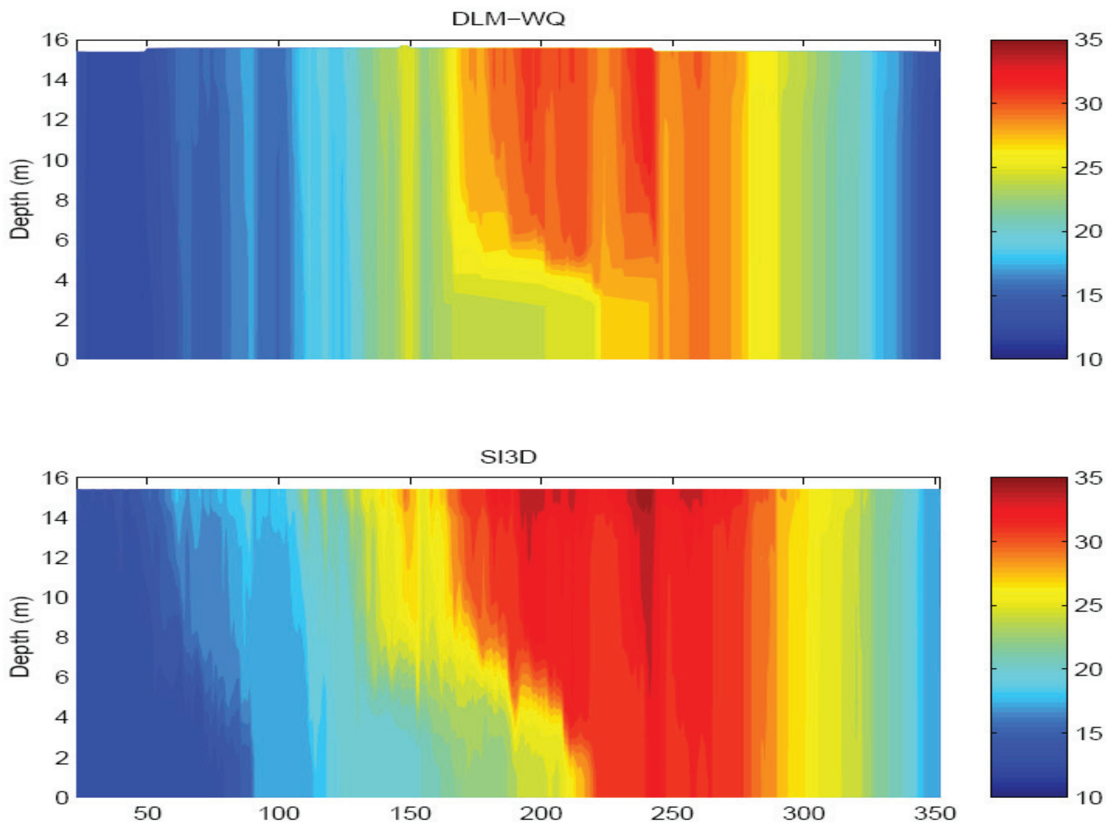

FIGURE D-14
COMPARISON OF TEMPERATURE SIMULATION BY DLM-WQ AND SI3D MODELS (DEGREES C)

Initial Conditions

The initial conditions for the Salton Sea were defined by data collected at Sampling Site 2 on January 22, 1999 as reported by Holdren and Montaño (2002). Dissolved oxygen ranged from 5 mg/L near the bottom to 10 mg/L at the surface. Dissolved orthophosphate was initialized at 2.5 μg/L (0.0025 mg/L) throughout the water column. Particulate organic phosphorus ranged from 61 μg/L (0.061 mg/L) at the bottom of the water column to 92 μg/L (0.092 mg/L) near the water surface. Nitrate concentrations ranged from 134 to 260 μg/L (0.134 to 0.260 mg/L), with lower concentrations near the bottom of the water column and higher concentrations near the water surface. Ammonia was initialized with higher concentrations near the bottom of the water column and lower concentrations near the water surface, ranging from 732 to 938 μg/L (0.732 to 0.938 mg/L). Salinity ranged from 43,500 to 44,500 mg/L. Initial chlorophyll *a* concentrations ranged from 13 to 23.5 μg/L (0.013 to 0.0235 mg/L) throughout the water column.

The water surface was initialized at 15.514 meters (50.42 feet) above the Sea Bed, or -227.7 feet msl, with the bottom of the water column at -278.6 feet msl, based on the Reclamation bathymetry data set and USGS reported water surface elevation for January 1999.

Meteorological Conditions

Data from three CIMIS stations around the Salton Sea were used to define the meteorological conditions for 1999 (CIMIS Stations # 127, 128, and 141). An area-weighted average wind field was calculated from data collected at these three stations to develop the daily average wind speed input to the DLM-WQ model. This was necessary because DLM-WQ requires a uniform wind field across the water surface. Data from station #127 were used as model inputs for air temperature, relative humidity, shortwave radiation, longwave radiation (calculated), and precipitation. It was assumed that variations between stations for these parameters would be negligible, whereas wind is highly spatially-variable, and the multi-dimensionality of wind can greatly influence convective mixing. Figure D-15 shows the variation in daily wind in 1999 between three CIMIS stations and area-weighted average wind fields calculated to be used with large, deep saline water bodies, such as the Salton Sea under Existing Conditions and No Action Alternative through 2020; Marine Seas in Alternatives 5, 6, and 7; and the Recreational Saltwater Lake in Alternative 7. This comparison shows the marked increase in the frequency of large wind speeds experienced at Station #128 versus Stations #127 or 141. All other parameters being equal, more frequent, higher wind speeds would increase mixing of the large, deep saline water body, which would impact resuspension of nutrients and stratification of the Sea.

Meteorological data for 1999 were compared to data from 1997 to 2005 to determine whether the 1999 conditions were representative of longer term conditions at the Salton Sea. Figure D-16 shows the annual frequency distribution of hourly wind speed at CIMIS Station #127 between 1997 and 2005. The data indicate that there is little variation in the frequency distribution of wind speed and that the data collected in 1999 are appropriate for use in analyses.

Physical Parameters

The one-dimensional, empirical nature of DLM-WQ requires a limited amount of physical parameters for input. Wind induced mixing processes are the dominant forcing mechanism in DLM-WQ. Five distinct mixing processes are included in the model.

These processes control the thermal stratification and the variability with depth of water quality parameters:

- Convective overturn;
- Stirring;

- Shear production;
- Energy requirement; and
- Billowing.

Kinetic Parameters

The water quality model is primarily controlled by kinetic rate constants specifying the rate of transformation of various components on the nitrogen and phosphorus cycles, as well as the dissolved oxygen and chlorophyll cycles. Kinetic rates, such as those specifying algal growth, respiration, death, and nitrogen mineralization and nitrification are collected in an input file. Control over the hydrogen sulfide production, oxidation, reduction, and volatilization is also included.

Table D-3 presents a summary of the kinetic parameter values used for the final calibration simulation and for all alternatives analyses, except the load reduction investigations discussed below. Several of these parameters were adjusted during the calibration phase of this modeling effort. These parameters include:

- Sediment oxygen demand;
- Parameters controlling release of nutrients from the sediment (pore water diffusion);
- Parameters controlling wind induced resuspension and contribution of orthophosphate and ammonia to the water column;
- Parameters controlling release and fate of hydrogen sulfide in the water column; and
- Parameters controlling the growth, respiration, and death of the algal biomass.

Sediment Oxygen Demand

The sediment oxygen demand (SOD) is specified as a constant demand in terms of grams of oxygen/square meter/day. Oxygen demand due to algal decomposition in the water column is included as part of the SOD. Calibration efforts required the use of a relatively high value for SOD of 10 grams of oxygen/square meter/day. This value was required to match observed oxygen profiles throughout the year at lower depths. Without this elevated value, the model predicted dissolved oxygen concentrations well above measured values in the lower portion of the water column. Considering that other oxygen demanding constituents, such as hydrogen sulfide and ammonia, were predicted at concentrations similar to expected values, the SOD used in the calibration appears to correctly account for additional oxygen demand not explicitly included in the model formulation.

Nutrient Release

The release of orthophosphate and ammonia from the sediments is simulated as a pore water diffusion process controlled by a specified release rate from the pore water of either orthophosphate or ammonia. The actual release rates are also influenced by temperature and dissolved oxygen levels. The release rate increases as temperature increases and dissolved oxygen decreases.

During the calibration effort, the temperature coefficient controlling the change in release rate with temperature was increased to more closely match the measured seasonal variation in pore water release of orthophosphate. Unfortunately, there is only one temperature coefficient in DLM-WQ that affects both the phosphorus and the nitrogen release. The decision was made to focus on matching the phosphorus release at the expense of nitrogen because the Salton Sea is phosphorus limited.

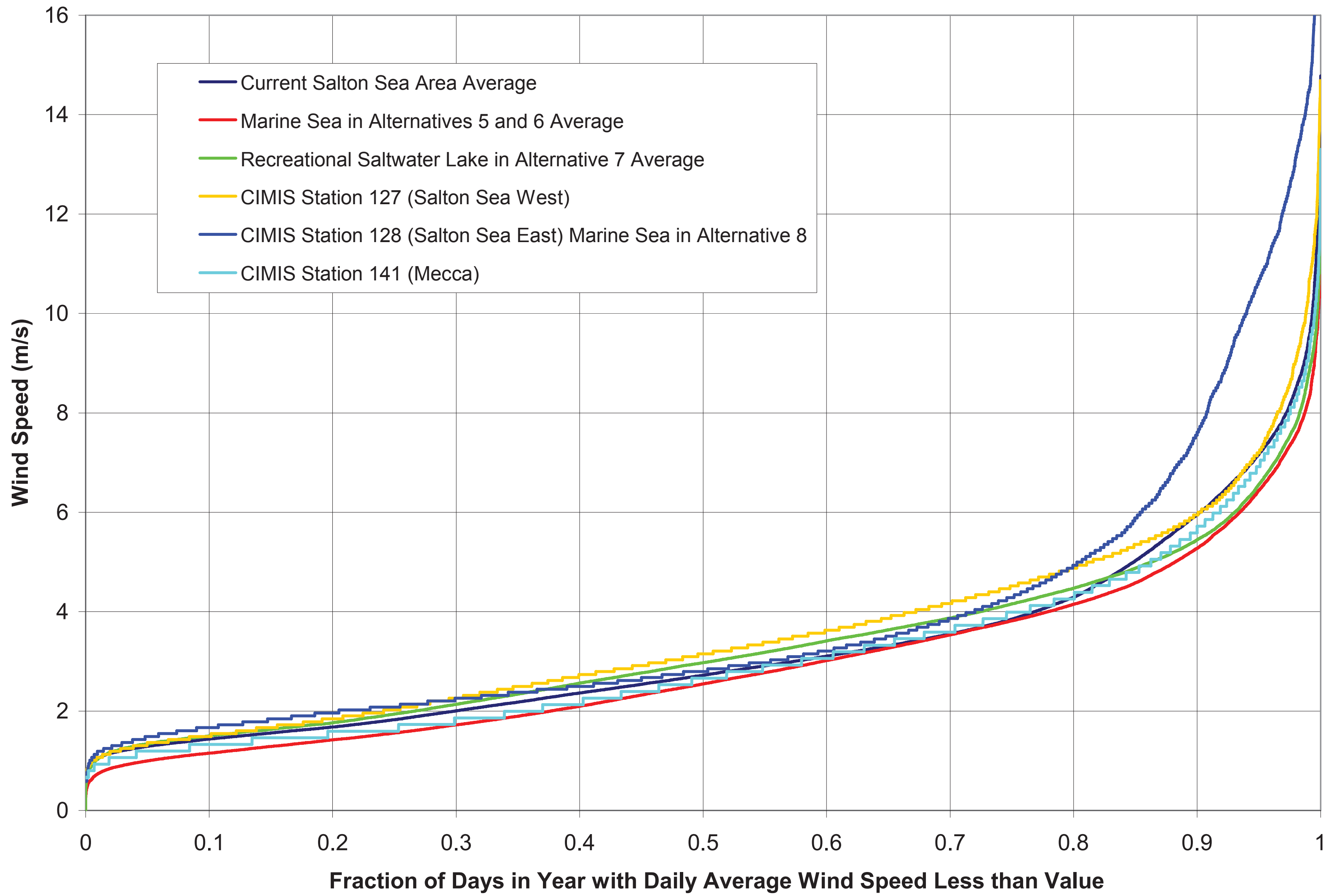

FIGURE D-15
COMPARISON OF DAILY AVERAGE WIND SPEED FREQUENCY FOR VARIOUS CONFIGURATIONS AND CIMIS STATIONS FOR 1999

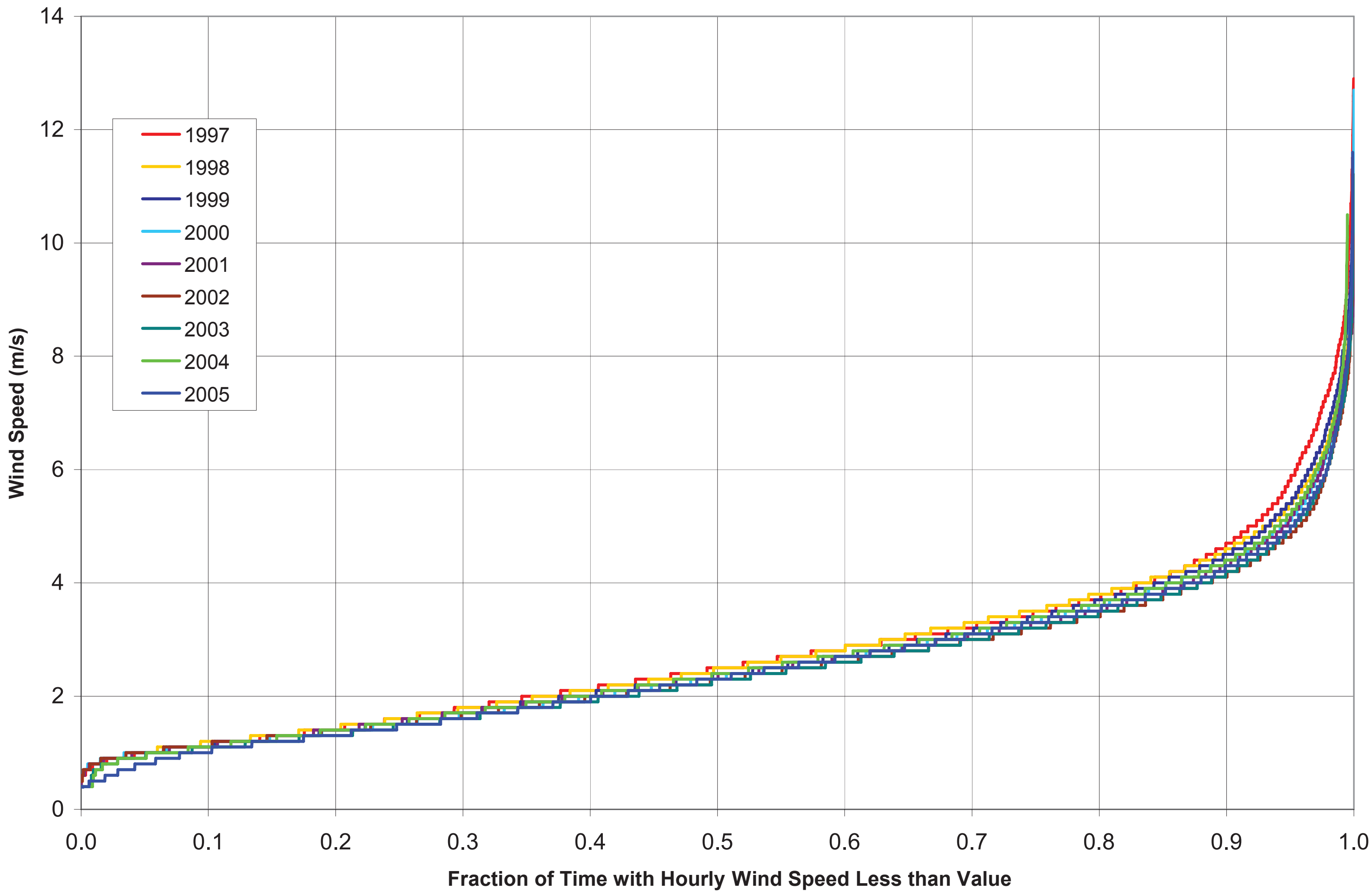

FIGURE D-16
COMPARISON OF WIND SPEED FREQUENCY
FOR CIMIS STATION #127 (1997-2005)

Table D-3
Summary of Kinetic Rates and Parameters used in Calibration Simulation

Parameters	Units	Values
Nutrient Utilization Parameters		
Phosphorus to chlorophyll *a* mass ratio		0.5
Nitrogen to chlorophyll *a* mass ratio		7
Half saturation constant for nitrogen nutrient limitation	µg/L	75
Half saturation constant for phosphorus nutrient limitation	µg/L	5
Other Parameters		
Maximum algal growth rate	1/day	3.5
Maximum algal respiratory rate	1/day	0.2
Maximum algal mortality rate	1/day	0.1
Temperature multiplier for growth, respiration, death, and permanent removal		1.068
Light attenuation of pure water in background	1/meter	0.52
Specific extinction coefficient for chlorophyll *a*	1/(meter-mg/L)	0.017
Specific extinction coefficient for particles	1/(meter-mg/L)	0.03
Light saturation for phytoplankton	watts/square meter	86
Setting velocity for phytoplankton, detritus, and particulate organic nitrogen	meter/day	0.1
Setting velocity for suspended solids, detritus, and particulate organic phosphorus	meter/day	3.25
Chemical Reaction Parameters		
Half saturation constant for limitation of reactions by dissolved oxygen for nitrification	mg/L of dissolved oxygen	1
Sediment oxygen demand of sub-euphotic sediments	grams/square meter/ day	10
Decomposition rate of dissolved oxygen	1/day	0.0025
Ammonification rate for particulate organic nitrogen conversion to ammonium	1/day	0.001
Nitrification rate for ammonium conversion to nitrate	1/day	0.2
Denitrification, nitrate conversion to nitrogen gas	1/day	0.5
Phosphorus conversion rate, orthophosphate conversion to particulate phosphorus	1/day	0.3
Phosphorus permanent removal rate	1/day	0.0000109
Sediment Parameters		
Release rate of phosphorus as total hydrolyzable phosphorus from sediments	mg/square meter/day	1.2
Release rate of nitrogen measured as ammonia from sediments	mg/square meter/day	6
Temperature multiplier for sediment nutrient release		1.3
Resuspension constant	µg/L	600
Resuspension exponent	meter/second	0.8
Ratio particulate phosphorus in suspended sediments		0.0025
Ratio particulate nitrogen in suspended sediments		0.11
Porosity of the sediments		0.8
Mixing elevation threshold	meter	10
Critical wind speed resuspension	meter/second	1.5

Table D-3
Summary of Kinetic Rates and Parameters used in Calibration Simulation

Parameters	Units	Values
Hydrogen Sulfide Parameters		
Oxidation of hydrogen sulfide	1/day	0.1
Bulk coefficient of hydrogen sulfide sink, complexation	1/day	0.0001
Sediment release coefficient of hydrogen sulfide	mg/square meter/hour	3.751
Sediment release coefficient of hydrogen sulfide (temperature influence)	mg/square meter/hour	0.292
Critical dissolved oxygen concentration for hydrogen sulfide reaction	mg/L	0.5
Organic phosphorus of pore water in sediments	µg/L	1
Ammonia of pore water in sediments	µg/L	8

Note: All values are presented in the units used in the model.

Nutrient Resuspension

The resuspension of nutrients is a wind-driven process that also depends on the concentration of orthophosphate and ammonia in the pore water. The process simulated in the model is a release of orthophosphate and ammonia contained in the pore water during sediment resuspension events. The magnitude of resuspension is controlled by three parameters: a minimum wind required for resuspension, a power function controlling the rate of change in resuspension with increases in wind speed, and orthophosphate and ammonia in the pore water. During the calibration process, the minimum wind speed allowed to resuspend sediments was lowered from the original value in order to increase the average orthophosphate concentrations in the Salton Sea. Regeneration of orthophosphate due to algal decomposition in the water column also is included in the model assumptions.

Also, the power law coefficient was decreased such that the sediment release increases more slowly with increases in wind speed. Without these adjustments, it was not possible to match measured orthophosphate and chlorophyll *a* concentrations in the Salton Sea. The reduction in minimum wind speed allowed for an increase in the average concentration in the Salton Sea, and the reduction in the power law coefficient allowed for a decrease in the magnitude of daily spikes in concentration associated with higher wind events.

Hydrogen Sulfide

The processes in the hydrogen sulfide module added to the DLM-WQ model for this analysis include a sediment release term, an oxidation loss term, a complexation loss term, and a volatilization loss term. The kinetic rate controlling the oxidation loss of hydrogen sulfide as it is converted to sulfate was adjusted during the calibration effort in order to gage the sensitivity of the model to this parameter. This parameter effectively controls how long elevated hydrogen sulfide concentrations persist in the water surface layers following the fall mixing event and breakdown of stratification.

The quantification of the release of hydrogen sulfide from the sediments was developed from field data (Anderson and Amrhein, 2002), and these parameters were not adjusted during the calibration phase. The volatilization routine used in the DLM-WQ model was similar to that used for ammonia volatilization, and was not adjusted during calibration. Finally, the complexation loss term was added as a bulk loss term. The kinetic parameter controlling this reaction was assigned a small rate that was not adjusted during calibration.

Algal Biomass

The algal biomass is controlled through specification of kinetic rates controlling the growth, respiration, and death of phytoplankton. These rates also indirectly influence the nutrient cycles, because nutrients are taken up by algal biomass during growth and returned during respiration and death. The primary adjustment during the calibration effort was to the algal growth rate. The growth rate was increased from 2.0 to 3.5/day in order to match measured chlorophyll *a* concentrations throughout the year. This rate is reasonable considering the optimal growing conditions in the Salton Sea.

Results of Model Calibration

This section describes the parameters involved in the calibration effort, including the methods by which each parameter was calibrated and the quality of the calibration. Sensitivity of the model to certain parameters is discussed where applicable. The discussion concludes with a presentation of summary metrics describing the general state of the Salton Sea with regards to temperature stratification, dissolved oxygen regime, chlorophyll *a*, nutrients, and hydrogen sulfide. A complete series of graphical output comparing predicted and observed values is contained in Appendix D, Attachment D1.

It should be noted that temperature, nutrients, dissolved oxygen, and chlorophyll are solved simultaneously in the model with feedback loops for all parameters. The model also assumes that recirculation flows originate from the bottom of the Sea Bed in the deep Marine Sea in response to releases of hydrogen sulfide and ammonia. However due to the algorithms in the model, the results are not sensitive to changes in this assumption.

Temperature

The temperature calibration was conducted to match a series of 17 vertical temperature profiles taken throughout 1999 (Holdren and Montaño, 2002). The observed profiles indicate a well mixed period followed by a relatively weakly stratified period, which eventually breaks down towards the end of the year.

The primary variable adjusted during the temperature calibration was a scaling factor applied on a uniform basis to the area-averaged wind field generated from the CIMIS data. The measured wind speeds are measured for winds over land. However, there is generally a need to adjust the measured wind speeds over land for wind speeds over water or at the water and land interface due to changes in friction coefficients and drag forces.

For the model used in the PEIR, wind speed was increased by about 33 percent to achieve temperature calibration. A combination of visual judgment of contour plots (predicted versus observed) and root mean square (RMS) error calculations on predicted and observed vertical temperature profiles were used to refine the calibration effort. Results of this effort are presented in Figure D-17 and Figures D1-1 through D1-3.

Figure D1-1 presents contour plots of the modeled and observed temperature regime in the Salton Sea for the calibration year, as well as a plot of the difference between the measured and predicted values. Results indicate that the model performs quite well with respect to temperature. The model adequately characterizes the build up of stratification in the spring, the strength of the stratification during the summer, and the timing of the breakdown of stratification in the fall. Figure D1-2 provides a time series plot of modeled, measured surface, and bottom temperatures. Again, the model performance is quite good, although it does seem to underestimate the strength of the stratification, expressed as the temperature difference between the surface and bottom waters. Figures D1-3A and D1-3B demonstrate model performance for the series of vertical profiles used in the calibration effort. The average RMS error value between measured and predicted values is 1.09 ˚C (1.96 ˚F) for all 17 profiles used in the calibration effort.

It also should be noted that increased thermal stratification does not necessarily resulted in decreased mixing. There could be mixing due to density currents that would not be represented by the thermal stratification in the model.

Phosphorus

Operating under the assumption that the Salton Sea is primarily phosphorus limited, the next major goal of the calibration effort was to reproduce measured orthophosphate concentrations in the surface and bottom waters throughout the simulation period. A total of 17 measurement pairs of surface and bottom orthophosphate concentration were available for calibration.

Sources of phosphorus adjusted during the calibration process included the sediment release of phosphorus (passive diffusion), controlled by a temperature dependent release rate specified in terms of milligrams/meter squared/day of orthophosphate released to the water column, and a wind dependent resuspension algorithm that controls the physical addition of phosphorus back to the water column by wind-induced currents at the sea floor. The resuspension of phosphorus is parameterized by a pore water orthophosphate concentration, and two variables controlling the minimum wind required for resuspension and the strength of the exponential relationship between wind speed and resuspension. Finally, the resuspension of phosphorus is assumed to occur only in sediments shallower than 10 meters deep.

Sinks of phosphorus adjusted during the calibration process included the rate at which orthophosphate is lost through sorption and co-precipitation to particulate phosphorus, and the rate and amount of orthophosphate taken up by algae through respiration for growth.

The sediment release rate of orthophosphate was altered to more accurately reflect the measured temporal variation of phosphorus release presented by Anderson and Amrhein (2002). The variable controlling the variation in the release rate with temperature was increased to provide a greater range of release rates through the year (high in summer, low in winter), while maintaining an appropriate annual average release rate.

The results of the orthophosphate calibration are presented in Figure D1-4. The field data indicate that the Salton Sea is generally uniformly mixed with respect to orthophosphate. There is a general decrease of orthophosphate concentration during the spring and summer months, except for two isolated events, which may be indicative of resuspension. Model simulations results show phosphorus concentrations higher than observed values during spring months. This could be due to limited ability to adjust the temporal and temperature based relationships. If additional data are collected in the future, the calibration may be more appropriate. Simulated concentrations match the lower end of the range of measured values throughout the summer and fall.

Sensitivity simulations were conducted on the phosphorus loads to the system. Through selective removal of each of the three sources (external loads, internal loads from sediment release, and internal loads from sediment resuspension), the model results indicated that the external loads and the loads from sediment release were not sufficient to support chlorophyll *a* as measured in the Salton Sea, and that considerable internal loads, aside from pore water diffusion, were required to accurately reproduce measured chlorophyll *a.* These results are related to the model assumptions and algorithms that related phosphorus and chlorophyll *a.* Therefore, if future changes are made to these algorithms or the calibration, the sensitivity of changing the different factors also may be different.

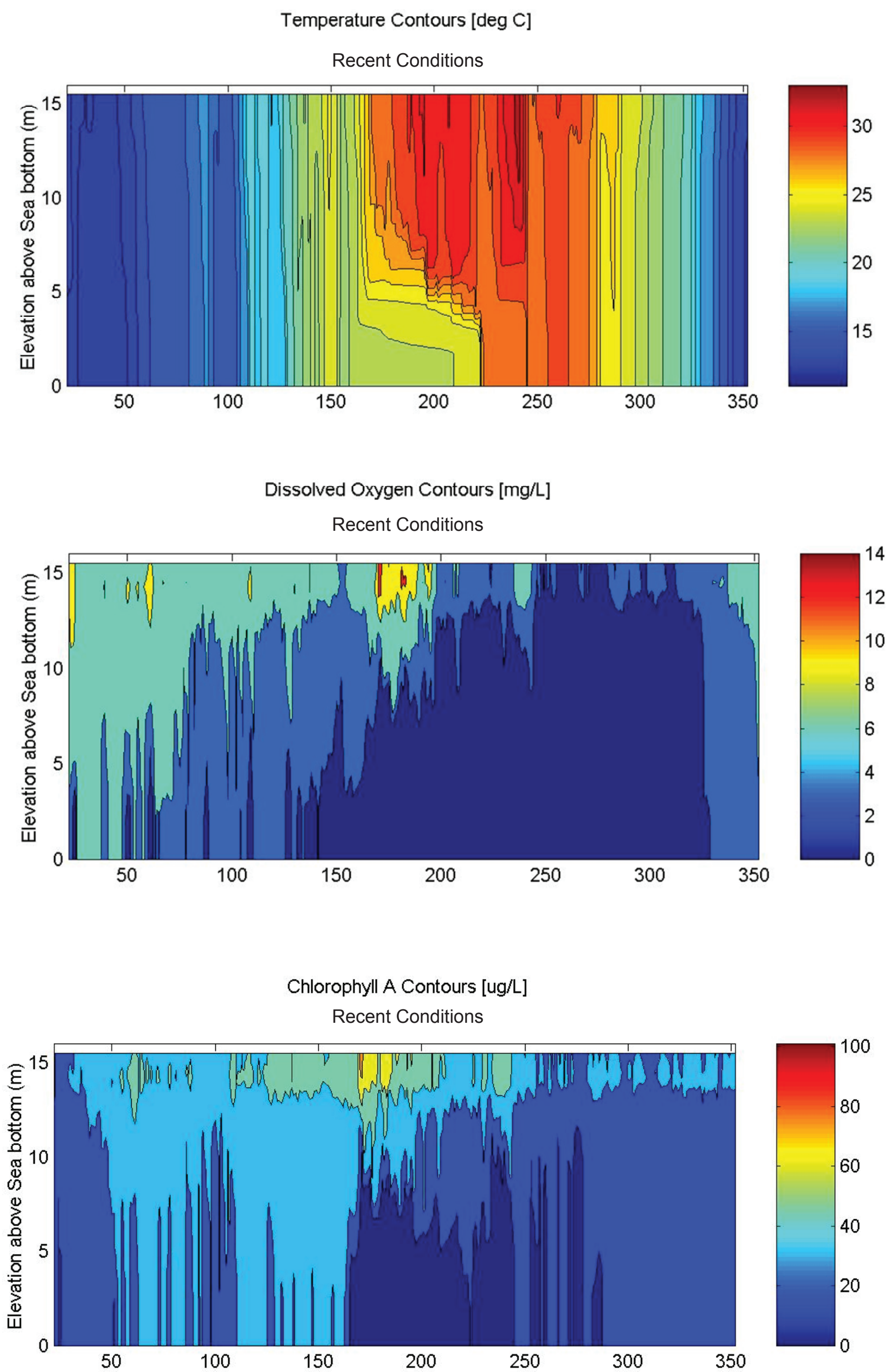

FIGURE D-17
MODELING RESULTS FOR TEMPERATURE, DISSOLVED OXYGEN, AND CHLOROPHYLL *A* FOR 1999

Nitrogen

Ammonia nitrogen and nitrate nitrogen were both calibrated to measured concentrations in the surface and bottom waters for the same 17 day data set described above. Sources of ammonia nitrogen adjusted during the calibration process included the rate at which ammonia is released from the sediment and the concentration of pore water ammonia that is resuspended to the water column via wind induced currents. Sinks of nitrogen adjusted during the calibration process included the rate at which ammonia mineralizes to nitrates and the amount of ammonia required for algal growth. Nitrate was calibrated through adjustment of the ammonia mineralization rate (source) and the rate at which nitrates convert to nitrogen gas (sink).

Results of the ammonia calibration are presented in Figure D1-5. Observed data indicate that the ammonia concentrations at the bottom water column are nearly twice those at the water surface and that peak concentrations occur in the bottom waters during the stratified period. Furthermore, field data indicate that the ammonia concentration is higher at the end of the year than at the start. Model results match the general trend of the ammonia field data. Predicted concentrations at the bottom of the water column are higher than the field data during the stratification period, indicating probably too high of a release rate of ammonia from the sediments.

If future models are modified to allow both temperature based changes for more than one nutrient factor, these issues could be reduced. An ammonia-specific temperature coefficient applied to the release rate would allow for a more refined calibration of ammonia. DLM-WQ currently only allows a single temperature coefficient controlling the release of both orthophosphate and ammonia. This coefficient was adjusted during the calibration of phosphorus, which was considered more critical to the nutrient dynamics at the Salton Sea.

Results of the nitrate calibration are presented in Figure D1-6. Nitrate field data indicate a gradual decrease in concentration from the start of the year into the summer months, and a gradual increase in concentration into the winter. Model results closely match the trend of the field data.

Chlorophyll

Chlorophyll *a* field data were collected at near surface, one-quarter depth, and roughly half-depth throughout the year. This data set, shown in Figure D1-7, was used for calibration. Chlorophyll *a* concentrations are fairly uniform with depth in the top half of the water column, and fluctuate throughout the year with a major peak in concentration in the summer months and another minor peak in the late winter (Julian Day [JD] 75).

Chlorophyll *a* concentrations were calibrated by adjusting the algal growth rates, algal respiration and mortality rates, algal settling velocity, algal composition (phosphorus and nitrogen), and half saturation coefficients for algal growth. In the DLM-WQ model, the limitation of phytoplankton growth rate due to environmental factors is modeled by multiplying the maximum potential phytoplankton growth rate by a temperature adjustment factor and a growth limiting fraction. The growth limiting fraction is the minimum value determined from equations for limitation by light, bio-available water column phosphorus, and bio-available water column nitrogen. User-specified chlorophyll *a* to phosphorus and nitrogen ratios are used to determine the amount of nutrients removed from the water column during algal growth.

Algal growth is limited in spring and summer by the availability of orthophosphate. In general, the model predictions perform quite well with respect to chlorophyll *a*. The model does not match the early spring spike in concentration, but does match the annual trend very well, including the increase in concentration during the summer period.

Dissolved Oxygen

Dissolved oxygen calibration data were available as vertical profiles throughout the water column taken on a series of days spread throughout the year. Dissolved oxygen was calibrated through adjustments to the chlorophyll *a* parameters discussed above, the SOD, and the phosphorus and nitrogen cycle parameters. Parameters governing the production and oxidation of hydrogen sulfide were also adjusted during the dissolved oxygen calibration process, considering the influence of hydrogen sulfide on the oxygen regime. The reaeration algorithm in DLM-WQ was investigated to determine its influence on the dissolved oxygen predictions. Results of the dissolved oxygen calibration are presented in Figures D1-8 through D1-10. A comparison of the evolution of the vertical dissolved oxygen profile is presented in Figure D1-8. This contour plot demonstrates the vertical and temporal extent of the low dissolved oxygen area in the Salton Sea. Model results closely match observed concentrations, and capture the duration and extent of low dissolved oxygen conditions. The model under-predicts the surface concentration of dissolved oxygen, and also underestimates the reaeration of the Salton Sea following the breakdown of stratification late in the year.

Figure D1-9 presents time series plots of modeled, observed surface, and bottom concentrations. Again, the model predictions match the near bottom concentration and the general trend of the near surface concentrations quite well. The reaeration scheme used by the model is hard-coded into the model, so that the user cannot adjust the parameters governing reaeration. This is a limitation of the model, as the Salton Sea is likely to have considerably wind-wave induced reaeration for which the model cannot account. The inability to match surface dissolved oxygen measurements may be related to the model's reaeration scheme.

Figures D1-10A and D1-10B, show the quality of the calibration against each of the 17 vertical profiles measured at the center of the Salton Sea. Overall, agreement is very good. The average RMS error of all vertical profiles of dissolved oxygen used in the calibration effort is 1.62 mg/L. Figures D1-11 through D1-13 present a comparison between model predictions at 6 a.m. and noon. Calibration was conducted with model output at noon to be consistent with field measurements. The 6 a.m. values are presented as a representation of minimum daily dissolved oxygen concentrations. Figure D1-12 shows that simulated dissolved oxygen concentrations at 6 a.m. could be more than 2 mg/L lower than those at noon.

Hydrogen Sulfide

The hydrogen sulfide module was added to DLM-WQ model specifically for the analysis in the PEIR. The module includes a temperature dependent release rate from the sediment, oxidation of hydrogen sulfide to sulfate, and a loss term reflecting complexation of hydrogen sulfide. The temperature-dependent release rate was derived from data reported by Anderson and Amrhein (2002). The oxidation of hydrogen sulfide to sulfate is related to the dissolved oxygen predictions such that the release of hydrogen sulfide creates an oxygen demand on the system. Although no data for hydrogen sulfide concentrations were sufficient for use in calibration of this parameter, Watts et al. (2001) reported concentrations on the order of greater than 5 mg/L at the bottom of the water column in the Salton Sea in July 1999 and 3 to 5 mg/L in August 1999. Adjustments were made to the appropriate kinetic rates to produce concentrations at the bottom of the water column within this range.

Discussion of the Calibration

The overall calibration provided a good match to measured profiles of both dissolved oxygen and temperature. Time series observations of orthophosphate, ammonia, nitrates, and chlorophyll *a* were all reproduced reasonably well by the model.

The model calibration effort required a rather high value of SOD in order to calibrate the dissolved oxygen concentration in the waters near the bottom of the water column. The model is also over-predicting ammonia concentrations in the waters at the bottom of the water column, which build up and exert a chemical oxygen demand on the overlying waters upon mixing. The addition of hydrogen sulfide to the model accounts for another chemical oxygen demand on the waters at the bottom of the water column. The required SOD in the model indicates an additional oxygen demand from the sediments that is not explicitly accounted for by hydrogen sulfide and ammonia. A sensitivity simulation was conducted with a SOD of 10 percent of the calibrated value and the resulting dissolved oxygen concentration predictions were 4 to 6 mg/L greater than observed values. This result indicates that the SOD in the Salton Sea is at the high end of values reported for other eutrophic lakes (USEPA, 1985). The high SOD rate could also be partially reflective of oxygen demands in the water column near the sediment-water interface that are not explicitly accounted for in the model.

A number of metrics quantifying the water quality in the Salton Sea have been developed for the PEIR for the purposes of comparing alternative simulations to the Existing Conditions simulation. For the purposes of the calibration, the data used was more indicative of Recent Conditions than Existing Conditions, as defined for the PEIR. Therefore, the information presented in the remaining portions of this appendix refers to the Recent Conditions model runs. The Recent Conditions model runs were not presented in Chapter 6 to avoid confusion with Existing Conditions.

Table D-4 presents a summary of the metrics for the Recent Conditions calibration simulation. Where possible, the measured value for the particular metric is included in brackets. However, due to the limited number of measurements in 1999, several metrics cannot be directly compared. The "goodness" of model calibration related to the key water quality parameters has been discussed above.

Table D-4
Water Quality Metrics in Model Run for Recent Conditions Calibration Simulation

Parameter	Metric	Target Value	Model Value for Recent Conditions	Measured 1999 value used in Calibration
Bathymetry	Maximum depth (meters)		15.5	Not Available
	Average depth (meters)		9.8	Not Available
	Water surface area (square kilometers)		940.,94	Not Available
	Volume (cubic kilometers)		9.190	Not Available
Salinity	Total dissolved solids (mg/L)	35,000	43,541	Not Available
Temperature	Water column annual minimum temperature (^{o}C)		12.4	Not Available
	Water column annual maximum temperature (^{o}C)		32.3	Not Available
	Water column annual mean temperature (^{o}C)		21.9	Not Available
	Number of days/year with temperature differences between the top and bottom of the water column greater than 2 ^{o}C		71	Not Available
	Number of consecutive days/year with temperature differences between the top and bottom of the water column greater than 2 ^{o}C		57	Not Available
Dissolved oxygen	Number of days/year with dissolved oxygen concentrations at the water surface at 6 a.m. of less than 2 mg/L	0	80	Not Available

Table D-4
Water Quality Metrics in Model Run for Recent Conditions Calibration Simulation

Parameter	Metric	Target Value	Model Value for Recent Conditions	Measured 1999 value used in Calibration
	Number of days/year with depth-averaged dissolved oxygen concentration at 6 a.m. of less than 5 mg/L	0	214	Not Available
Phosphorus	Annual mean total phosphorus concentration (µg/L)	less than 35	66	69
Nitrogen	Mean ammonia concentration in summer (mg/L)	less than 1	1.5	1.5
Chlorophyll *a*	Mean chlorophyll *a* concentration in summer (µg/L)	less than 12	30	41
	Annual mean chlorophyll *a* concentration		31	35
Hydrogen sulfide	Maximum hydrogen sulfide concentration at the water surface (mg/L)	less than 0.05	0.13	Not Available
	Number of days/year with water surface hydrogen sulfide concentration greater than 0.05 mg/L	0	6	Not Available
Trophic Status	Carlson Trophic State Index	50 to 60	65	65

Notes: All values are presented in the units used in the model.
The following conversion factors can be used for the units presented in this table: 1 meter = 3.25 feet, 1 squared kilometers = 242.5 acres, 1 cubed kilometers = 788,065.3 acre-feet, and 1 µg/L = 0.001 mg/L. To convert ^{o}C to ^{o}F, multiply ^{o}C by 1.8 and add 32.

The 1999 calibration simulation indicates that the Salton Sea is moderately thermally stratified for 71 days, with 57 of those days occurring consecutively. The model simulations reproduce the dissolved oxygen regime in the Salton Sea that has been observed to have negative effects on fisheries, as there are 80 days predicted in the model in which the dissolved oxygen concentration at the surface in the early morning hours (6 a.m.) is below 2 mg/L.

The annual simulated mean total phosphorus concentration, reported on a depth-averaged basis, is 66 µg/L (0.066 mg/L) which compares well to the measured value of 69 µg/L (0.069 mg/L), but is higher than the CRBRWQCB TMDL target of 35 µg/L (0.035 mg/L) (see Chapter 6 for discussion of TMDLs). The annual average chlorophyll *a* concentration is 31 µg/L (0.031 mg/L) and compares well to the measured value of 35 µg/L. The mean summer chlorophyll *a*, averaged from June 21 through September 21 (Julian day 172-264), is 30 µg/L (0.030 mg/L) and is lower than the measured value of 41 µg/L. While the model captures the trend of spring-summer trends well, it does not track as well for the short-duration algal blooms. The mean summer chlorophyll *a* value is higher than the CRBRWQCB TMDL monitoring target of 12 µg/L (0.012 mg/L), with a range of 7 to 20 µg/L (0.007 to 0.020 mg/L). The Carlson TSI for the Salton Sea based on model simulated total phosphorus is 65 and when based on simulated chlorophyll *a* concentrations is 64. The CRBRWQCB TMDL target TSI, designed to change the trophic state of the Salton Sea from hypereutrophic to eutrophic, is 50 to 60. The CRBRWQCB determined that to change the trophic condition of the Salton Sea to eutrophic from hypereutrophic, the mean phosphorus level in the Salton Sea would need to be reduced to 35 µg /L (0.035 mg/L).

MODEL SENSITIVITY TO KEY NUTRIENT LOADING PROCESSES

The DLM-WQ model considers three major sources of nutrient loading to the water column: (1) external loads supplied from rivers and drains, (2) internal sediment release via diffusive flux from the sediment layer, and (3) resuspension of sediments. The sediment release process in the model simulates the continual diffusion of dissolved nutrients into the pore water through the sediment/water interface. This process is controlled in the DLM-WQ through the specification of a loading rate, expressed in mg/square meter/day. This loading rate increases with temperature and decreases with dissolved oxygen concentrations. Thus, warm, anoxic bottom water in the summer months yield the greatest loading rates of both orthophosphate and ammonia from the bottom sediments. The sediment resuspension process involves the physical resuspension of sediments and associated pore water by wind-induced bottom currents. In DLM-WQ, user-defined sediment porosity and pore water concentrations control the amount of orthophosphate and ammonia entering the water column during resuspension events. The frequency and magnitude of resuspension is controlled through coefficients specifying the minimum wind for resuspension and a power law coefficient relating the increase in resuspension to the increase in wind speed. Processes contributing to the accumulation of nutrients in the sediment layer include the settling of particulate forms of nitrogen and phosphorus, especially in algal matter.

Model simulations were conducted to determine the sensitivity of the model to variations in the external and internal phosphorus loads. However, the DLM-WQ model suffers from the limitation that the sediment and water column nutrient processes are not dynamically coupled. Thus, the sediment pool which releases nutrients to the water column and the pool that serves as a sink for nutrients do not interact. The model assumes an infinite supply of nutrients in the sediments available for release into the water column.

Relative Importance of Loading Sources

A sensitivity analysis was conducted on the Recent Conditions simulation. Inflow concentrations of orthophosphate and particulate organic phosphorus were reduced by 50 percent and 100 percent in successive simulations, but without a reduction in the internal loads. Results indicate that the reduction of inflow phosphorus alone, without an accompanied change in the internal loading, has little influence on the water column phosphorus concentrations, as shown in Figure D-18. The model indicates that internal sources of sediment release and resuspension, if de-coupled from the external supply of nutrients, are sufficient to keep the Salton Sea in a highly eutrophic state, nearly identical to the Recent Conditions simulation, despite the complete removal of external phosphorus loads. However, internal phosphorus loads would be expected to gradually decline due to permanent loss to the sediments through precipitation/co-precipitation, burial of settled algae, sequestration in the form of fish bones and shells, and other processes. The model, however, does not account for reduction in supply of nutrients from the sediments due to the decoupled sediment-water column structure.

A second series of sensitivity studies was conducted with reductions in both internal and external loads of phosphorus. In this series of simulations, the internal loads associated with both sediment resuspension (and associated pore water) and diffusion of pore water into the water column were reduced by 50 percent to match the 50 percent reduction in the external phosphorus loads. The loading associated with sediment resuspension is controlled by a specification of the pore water concentration in the sediments. Results indicate that the combined reduction in both internal loads has a significant affect on the Salton Sea.

A final simulation was conducted to show which internal load is more significant. This simulation completely removed the sediment release (pore water diffusion) load, leaving just the reduced loads associated with sediment resuspension and the reduced external loads.

Orthophosphate concentrations at the surface were determined for the following simulations: Recent Conditions, 50 percent reduction only in external loads, 50 percent reduction in both internal and external loads, and 50 percent reduction in external loads with a 100 percent reduction in the sediment release (pore water diffusion) load, as shown in Figure D-19. Results indicate that the internal load associated with sediment resuspension and associated mixing of pore water with the water column is the most significant load of phosphorus. Reductions in external loads alone had little effect on water column orthophosphate concentrations and the complete removal of the sediment release load associated with pore water diffusion did not significantly alter the results. Predicted total phosphorus concentrations for the simulations discussed above are presented in Figure D-20.

However, it should be noted that this analysis has assumed that the internal loads are independent of the external loads. This assumption will certainly not hold in the long term as the source of nutrients in the sediments is reduced due to loss mechanisms (precipitation, co-precipitation, sorption, permanent burial, etc.). Rather, this analysis suggests that the internal sources (particularly sediment resuspension) currently dominate the total nutrient loading to the Salton Sea and that reductions in external loads are not likely to have an immediate response. The *timing* of water column response to changes in the external loads cannot be addressed through the modeling due to a de-coupling of the water column and sediment processes in the DLM-WQ model, the incomplete understanding and quantification of the principal loss mechanisms, and inadequate data to project how these loss mechanisms may change as the Salton Sea salinity and geochemistry is altered in the future. The section that follows addresses the expected timing (or delay) of changes in the Salton Sea water column phosphorus concentrations in response to reductions in external loads.

EXPECTED RESPONSE TO REDUCTIONS IN EXTERNAL NUTRIENT LOADS

Lakes are somewhat predictable in behavior. Comparative lake studies demonstrate the importance of influent loads and lake depth in determining lake water quality (Reckhow et al., 1992; Lee et al., 1978). In general, those studies showed that shallow lakes, such as the Salton Sea, tend to be eutrophic, yet highly variable.

Although hyper-saline and hypereutrophic, the Salton Sea fits into these general relationships by showing traditional and predictable algal growth responses to nutrient loading and lake morphometry. The calibration of the 1-D water quality model demonstrates those characteristics of the Sea.

The shallow water depth coupled with high fetch and strong winds of the Salton Sea are important characteristics, along with high nutrient loads likely to affect future water quality improvements. In general, release of stored phosphorus from the sediments of shallow lakes is highly significant in controlling lake water quality. High sediment temperatures that enhance microbial nutrient processing, enhancement of sediment resuspension over large areas of the lake, and quick transport of resuspended particles and pore water into the photic (algae growing) zone all cause phosphorus in the sediment to be a major controlling factor in the eutrophication of shallow lakes, including the Salton Sea.

Mediating factors include removal mechanisms of phosphorus, including co-precipitation with calcium carbonate (calcite), formation of hydroxyapatite in the sediments, permanent burial, and removal by incorporation into animal tissues. In addition, although it is not reflected in the 1-D model, the extensive shallow areas of the Salton Sea that may remain unstratified during times of stratification in deeper portions of the Salton Sea are likely to experience alternating periods of sediment anoxia and full mixing. These conditions commonly occur in shallow, eutrophic lakes and continuously resupply sunlit surface waters with remineralized sediment nutrients. Both periodically anoxic and shallow areas of eutrophic lakes contribute phosphorus to support algal growth (Cooke et al., 1993). However, data from Anderson and Amrhein (2002) indicate that the shallow areas of the Salton Sea have lower concentrations of phosphorus than deeper areas.

The 1-D model results could be used to predict conditions for defined sets of input parameters but not to easily predict changes over time, particularly in terms of estimating response times for changing water quality as affected by changed external nutrient loads. A bracketed series of results were presented to capture the expected range of lake response. However, although the 1-D model does not predict the lag

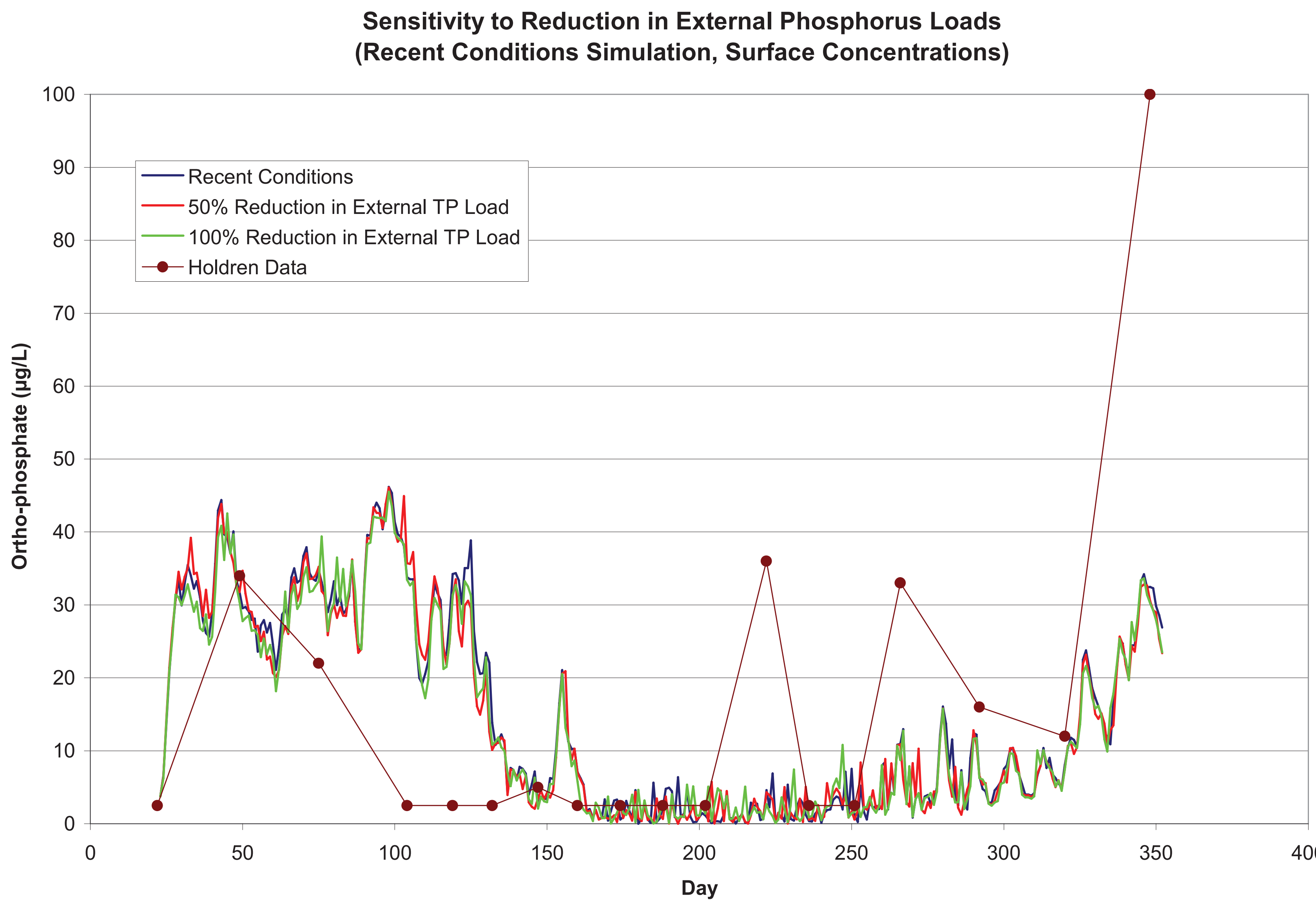

FIGURE D-18
SENSITIVITY ANALYSIS ON REDUCTION IN EXTERNAL PHOSPHORUS LOADS: ORTHOPHOSPHATE

time in the response to changing nutrient inputs, the limnological literature on lake restoration can be used to expand the predictions of likely lake responses.

Anderson and Amrhein (2002) state that a given reduction in external loads of phosphorus would cause a net reduction of loading to the Salton Sea twice that of the reduction in external loads and that a new equilibrium condition could be achieved in 3 years. This conclusion assumes that the internal phosphorus loads are directly (and instantaneously) proportional to the external loads, such that a reduction in external loads reduces the loads to the sediment layer, and the related internal loads from the sediment layer back to the water column. Schladow (2004) has argued that sediment resuspension may have a much larger impact on Salton Sea phosphorus concentrations and would limit the effectiveness of external load reductions - effectively, that lakes with large internal load mechanisms will respond slower than those primarily dominated by external loads. The principal scientific disagreement is how rapidly and to what extent the internal nutrient sources would respond to reductions in external loads.

In general, frequent resupply of sediment-generated nutrients to the photic zone is a characteristic of shallow lakes (Cooke et al., 1993). This characteristic interferes with lake restoration efforts because reductions in influent nutrients appear to have little effect on lake water quality over the short term. For example, in a shallow water body with a maximum depth of 8.2 meters (26.7 feet), eutrophic Kezar Lake in New Hampshire did not respond to a 71 percent reduction in external nutrient inputs for 8 years following the load reductions both with and without the addition of partial water treatment of lake sediments with alum addition (Connor and Martin, 1989). Similarly, there have been many cases of lake restoration where external loads were reduced but the lakes did not improve because of high levels of internal phosphorus loading (Downing et al., 2001; Phillips et al., 1994; Cooke and Kennedy, 1981). The lack of lake response may extend to 20 or 30 years (Charboneau, 2006; Sondergaard et al., 2003). However, the lake water quality must eventually change as the water body moves from one that was storing excessively supplied nutrients to a water body in which the internal sources are being depleted. In the case of the Salton Sea, a new equilibrium probably would be achieved with projected 50 and 90 percent reductions in external loads. It is expected that the time for lake response to a less-productive equilibrium state would be longer than 10 years. During project-level analyses, additional data collection and use of a dynamic, linked water and sediment quality model would be required to estimate the time for lake restoration following external nutrient reductions.

There are very few long term monitoring programs for similar lakes, and therefore it is not possible to develop a predictive, quantitative relationship that could be used for the PEIR alternatives. In addition, the Salton Sea has a unique blend of marine algae and lacks rooted aquatic plants that are typical of shallow, eutrophic lakes. The Salton Sea does not fit the classic condition of shallow lakes which typically trade off between domination by algae or macrophytes. In addition, although high sediment resuspension is a common characteristic of shallow lakes, the Salton Sea is considerably deeper and larger than most of the shallow lake examples from the restoration literature.

A common approach to the anticipated delay in restoration response has been to recognize that high levels of internal loading would be a significant impediment to lake restoration and that external load improvements must be coupled with internal load reductions to create a timely improvement in lake water quality. For that reason, lake restoration projects for shallow, highly eutrophic lakes typically involve the treatment or removal of in-place sediments in addition to nutrient input reductions (USEPA, 2006; USEPA, 1995; Downing et al., 2001; Charboneau, 2006). Such in-lake sediment treatments include sediment dredging (including deepening), capping, and alum or other chemical treatments (Cooke et al., 1993).

DLM-WQ MODELING FOR ALTERNATIVES

Water quality characteristics of the alternatives are described below, followed by a presentation of results of the modeling analysis for each alternative. Each alternative is compared to the Recent Conditions calibration simulation. A discussion of water quality metrics follows, quantifying the differences between alternative simulations in terms of thermal stratification, dissolved oxygen regime, nutrient concentrations, and trophic state.

A full graphical presentation of results, including contour plots, vertical profile plots, and time series plots of surface and bottom conditions, are compiled in Attachment D2. Contour plots demonstrating the temporal variation of vertical profiles for individual model parameters are presented for temperature, dissolved oxygen, chlorophyll *a*, hydrogen sulfide, and ammonia. Vertical profiles of predicted temperature are presented for 17 days throughout the one-year model simulation, allowing comparison of the alternative simulation and the Recent Conditions simulation. Profiles of dissolved oxygen are also presented for the same set of days. Time series plots compare model results of the alternative simulation to the Recent Conditions simulation for temperature, dissolved oxygen, chlorophyll *a*, orthophosphate, ammonia, and hydrogen sulfide at the water surface and bottom of the water column.

Scenario Approach

Since it is uncertain exactly how nutrient concentrations in the rivers and drains may change in the future due to watershed controls and how quickly the lake water quality may reach equilibrium with the new external loads, three scenarios are provided to bookend the future conditions. One scenario (Scenario A) represents water quality conditions, both inflow and sediment sources, that most closely reflect the current state of the Salton Sea. A second scenario (Scenario B) is included to approximate future water quality conditions at equilibrium with reduced external source loading. Finally, a third scenario (Scenario C) is included to approximate conditions with aggressive treatment of inflow nutrient concentrations, combined with watershed reductions. A description of each of the scenarios is provided below.

Scenario A

Scenario A best reflects the current water quality conditions at the Salton Sea. Nutrient concentrations in the rivers and drains are assumed to be identical to those used in the Recent Conditions calibration simulation. Similarly, nutrient pore water concentrations, sediment nutrient fluxes, and sediment oxygen demand are those incorporated from the Recent Conditions assessment. It should be noted that while the source nutrient concentrations are identical to 1999 conditions, this scenario does not equate to the same external nutrient loads as the 1999 conditions due to the reduction in flows in the future. This scenario may be used to approximate future conditions if no reductions in external nutrient concentrations occur or may represent the early phases of a project prior to achieving water column responses due to external load reductions.

Scenario B

Scenario B reflects another possible bookend in which inflow phosphorus concentrations are reduced by 50 percent and all internal sources respond by a like amount. The underlying assumption in this scenario is that reduced external loads would eventually translate into reductions in internal loads and improvements in water column phosphorus. It is assumed that a new equilibrium with the reduced loads has been reached. The following changes are considered in the modeling scenario:

- Reduction in external loads of 50 percent via reduction of inflow phosphorus concentrations;
- Reduction in internal (resuspension) nutrient loads of 50 percent via reduction in pore water concentration of orthophosphate and ammonia;
- Reduction in internal (diffusion) load of 50 percent via reduction in sediment release rate of orthophosphate, ammonia, and hydrogen sulfide; and
- Reduction in SOD of 50 percent to account for reduction in loads to the sediment.

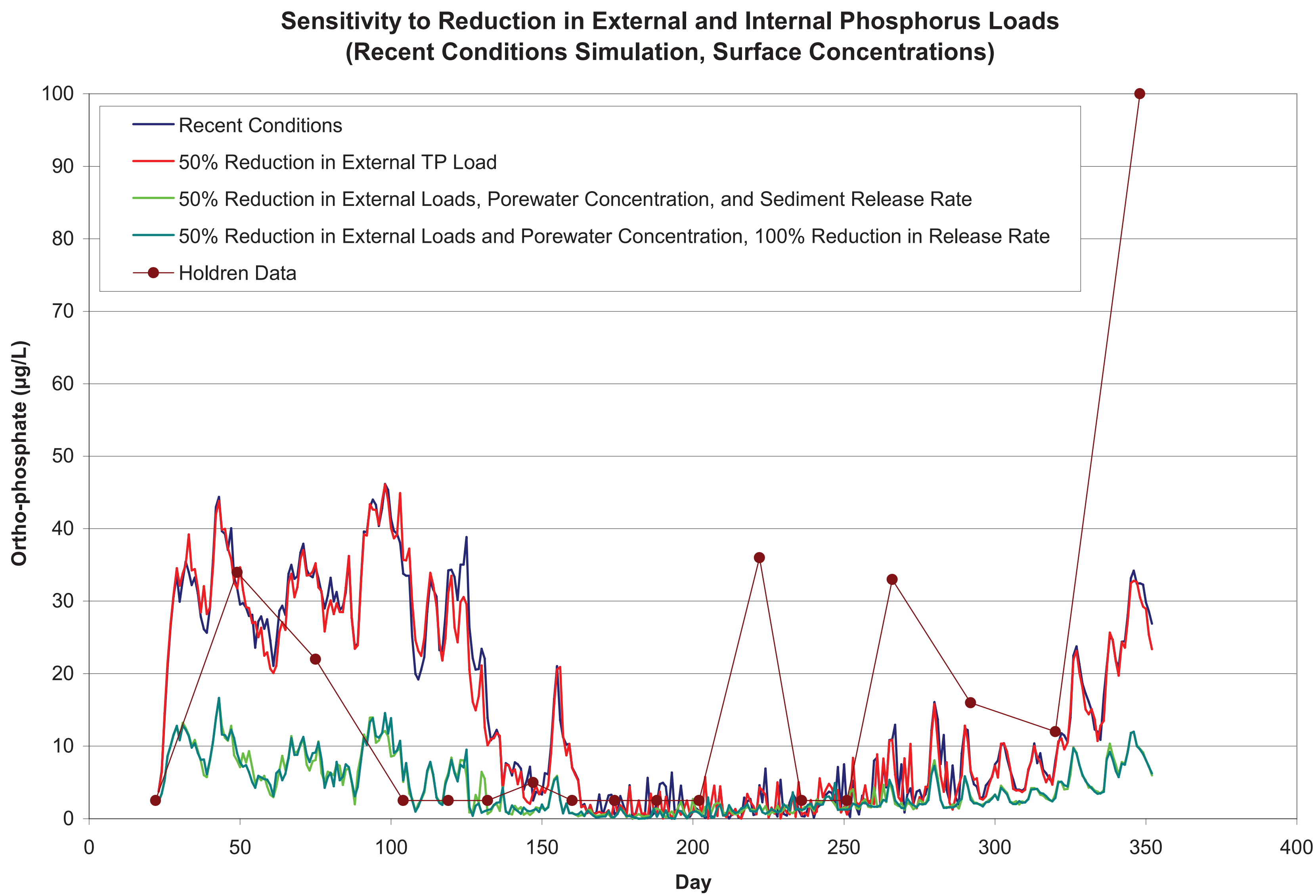

FIGURE D-19
SENSITIVITY ANALYSIS ON REDUCTION IN INTERNAL AND EXTERNAL PHOSPHORUS LOADS: TOTAL PHOSPHORUS

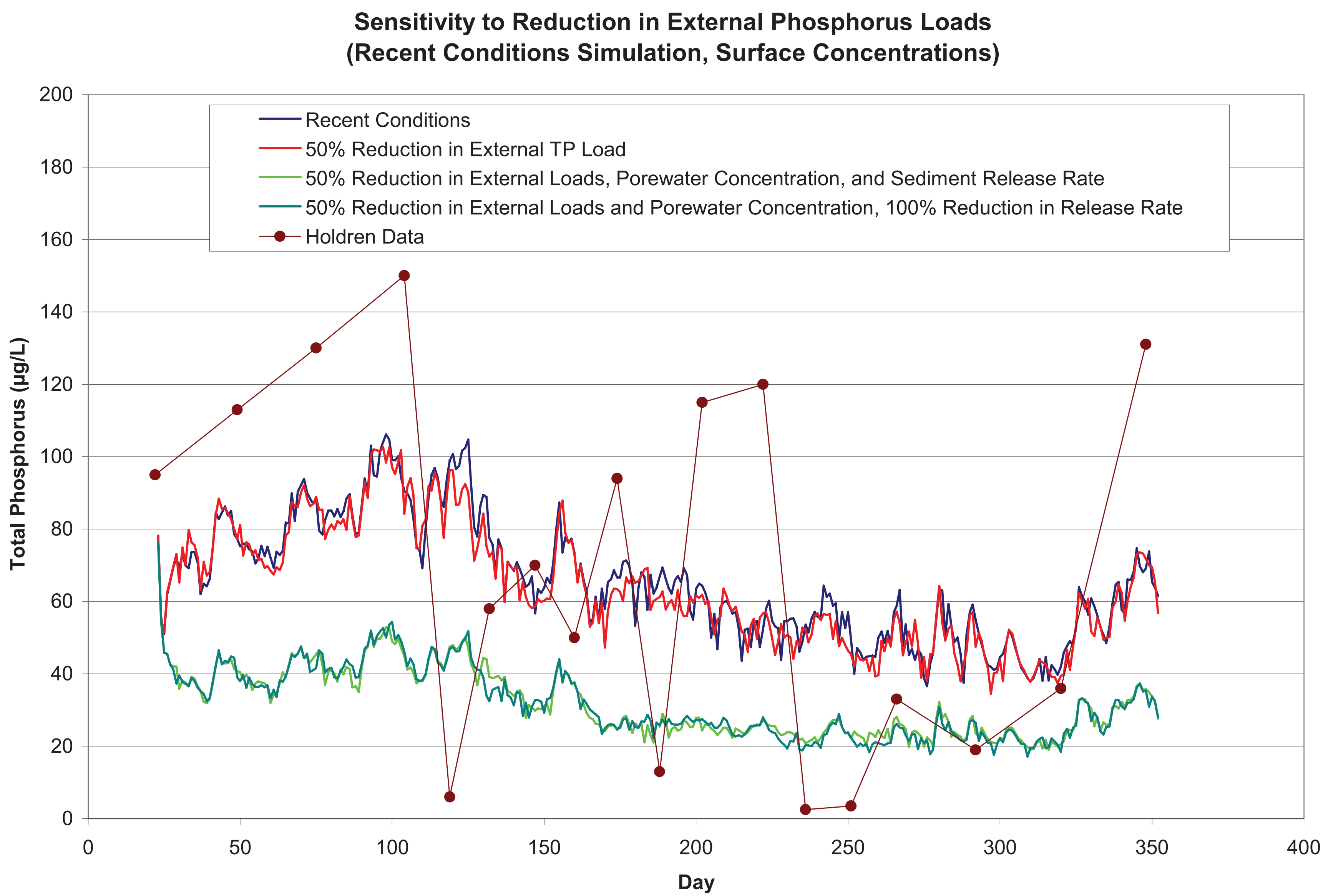

FIGURE D-20
SENSITIVITY ANALYSIS ON REDUCTION IN INTERNAL AND EXTERNAL PHOSPHORUS LOADS: TOTAL PHOSPHORUS

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Scenario C

Scenario C reflects an extreme bookend in which inflow phosphorus concentrations are reduced by 90 percent and all internal sources respond by a like amount. This scenario was only analyzed for Alternative 7 due to the inclusion of phosphorus treatment of inflows. The capability of achieving such reductions has not been evaluated. The underlying assumption in this scenario is that reduced external loads would eventually translate into reductions in internal loads and improvements in water column phosphorus. It is assumed that a new equilibrium with the reduced loads has been reached. The following changes are considered in the modeling scenario:

- Reduction in external loads of 90 percent via reduction of inflow phosphorus concentrations;
- Reduction in internal (resuspension) nutrient loads of 90 percent via reduction in pore water concentration of orthophosphate and ammonia;
- Reduction in internal (diffusion) load of 90 percent via reduction in sediment release rate of orthophosphate, ammonia, and hydrogen sulfide; and
- Reduction in SOD of 90 percent to account for reduction in loads to the sediment.

Assumptions for the Alternatives

The assumptions are described for the No Action Alternative, alternatives with a Marine Sea (Alternatives 5, 6, 7, and 8), and shallow water habitats in the Saline Habitat Complex (Alternatives 1, 2, 5, 6, 7, and 8) and in other water bodies (Alternatives 3 and 4).

No Action Alternative

The No Action Alternative simulation was based on the No Action Alternative-Variability Conditions with declining water surface elevations and increasing salinity. No changes were made to the geometric configuration of the Salton Sea other than the lower water surface. Three snapshots in time under the No Action Alternative scenario were considered in this study: water years 2020 (end of Phase I), 2040 (end of Phase III), and 2078 (end of Phase IV).

The projected salinity in these model runs for the Salton Sea was 69,000 mg/L in 2020, 231,000 mg/L in 2040, and 289,000 mg/L in 2078. These projections were based on hydrologic modeling of projected inflows and climate conditions. The DLM-WQ model had difficulty simulating conditions with salinity greater than 200,000 mg/L, therefore, simulations with salinities higher than 200,000 mg/L were simulated at 200,000 mg/L rather than the projected salinity. All other inflow and initial conditions for water quality constituents remained the same from the Recent Conditions simulation to the No Action Alternative simulations.

Alternatives 5 and 6

The same simulation was used for Alternative 5 (North Sea) and Alternative 6 (North Sea Combined) which included a large Barrier that separates a northern Marine Sea from the Brine Sink and a smaller, recirculation lake and/or channel in the southern Sea Bed. Water would be conveyed from the northern Marine Sea through a diversion on the southeastern portion of the lake to the southern marine water body where it is mixed with incoming water from the New and Alamo rivers, then conveyed back to the southwestern end of the Marine Sea. This recirculation pattern is designed to enhance mixing, and control nutrient and salt loading to the Marine Sea.

In Alternatives 5 and 6, the northern Marine Sea is proposed to be suitable for recreation and a healthy aquatic marine habitat. The Brine Sink would become increasingly saline as spill water from the Marine

Sea continuously adds more salt. The Marine Sea water surface elevation is targeted to be held constant at -70 meters (-230 feet) msl. Hourly CIMIS wind data from Stations #127, 128, and 141 were used to create an area-weighted average daily wind field for this simulation. The inflows to the Marine Sea are the Whitewater River and a combined inflow, which incorporates a blend of New and Alamo rivers, direct drains, creek inflows, and recirculation flows.

All water quality initial conditions remained the same in this simulation as in the Recent Conditions simulation with the exception of salinity. The northern Marine Sea salinity would be maintained at about 35,000 mg/L in the model. Inflow water quality from the Whitewater River, with the exception of salinity, is the same as under Recent Conditions. The recirculation flow concentrations for orthophosphate, particulate organic phosphorus, ammonia, and nitrate were calculated based on blending the observed 1999 New and Alamo rivers water quality with concentrations for the bottom of the water column in the Salton Sea from a previous simulation. Dissolved oxygen concentrations in the recirculation water were approximated with the observed 1999 Alamo River concentrations.

Alternative 7

In Alternative 7, a larger Marine Sea in the northern half of the Sea Bed would be created with the construction of a large Barrier near the centerline of the Sea Bed. Similar to Alternatives 5 and 6, recirculation through channels and a small Marine Sea in the southern Sea Bed would be used to control water quality and mixing in the northern Marine Sea. A Brine Sink would be located south of the northern Marine Sea.

The northern Marine Sea is proposed to be suitable for recreation and a healthy aquatic marine habitat. The Brine Sink would become increasingly saline as spill water from the Marine Sea continuously adds more salt. The Marine Sea water surface elevation is targeted to be held constant at -70 meters (-230 feet) msl. Hourly CIMIS wind data from Stations #127, 128, and 141 were used to create an area-weighted average daily wind field. The inflows to the north Marine Sea in this alternative are the Whitewater River, and a combined inflow which incorporates a blend of New and Alamo rivers, direct drains, creek inflows, and recirculation flows.

Alternative 8

In Alternative 8, a large Barrier would separate a southern Marine Sea from the Brine Sink and a smaller, recirculation lake and channels in the northern end. Water would be pumped out of the southern Marine Sea on the northeastern end and channeled through to the small, northern Marine Sea, where the water is mixed with incoming Whitewater River water, then conveyed back into the southern Marine Sea at the northwestern end. This recirculation pattern is designed to enhance mixing, and control nutrient and salt loading to the Marine Sea.

Daily CIMIS wind data from Station #128 were used to define the average daily wind field for this alternative. The inflows to the Marine Sea are New and Alamo rivers, a blend of direct drain and creek inflows (“other” inflows), and recirculation flows. Water quality for the New and Alamo rivers were the same from the Recent Conditions simulation as the Alternative 8 simulation. The recirculation nutrient concentrations were calculated by blending Whitewater River concentrations with concentrations from Marine Sea. New River concentrations from the 1999 data for dissolved oxygen were used for the recirculation flow. The water quality for the combined “other” inflows term used the Alamo River data from 1999.

Concentric Rings, Concentric Lakes, and Saline Habitat Complex Cells

The Concentric Rings (Alternative 3), Concentric Lakes (Alternative 4), and Saline Habitat Complex cells were simulated as individual cells assumed to be 1 square mile (640 acres) in area. Constant depths were specified at 2 meters (6.6 feet) for the Salinity Habitat Complex cells and Concentric Lakes, and 3 meters

(9.8 feet) for the Concentric Rings. While this geometrical configuration does not necessarily capture that of the Concentric Rings and Concentric Lakes, it is assumed that this approximation represents a conservative approach toward assessment of water quality in these water bodies. The longer fetch in the Rings and Lakes may increase the degree of mixing identified in these approximations.

Inflows to the cell were developed to match evaporation rates, and then increased by 20 percent to allow for flow through the cells. Meteorological inputs from the Alternative 8 simulations were used for these simulations. Inflow concentrations for all parameters were assumed to be equal to the conditions in the Alamo River.

In addition to the DLM-WQ simulations, the water quality characteristics of the Saline Habitat Complex cells were also described using the EUTROMOD model (Reckhow, 1996), which includes a large, comparative lake and pond database for North America. As discussed previously, EUTROMOD is an empirical model that consists of a series of regression relationships that use influent nutrient chemistry, hydraulic retention time, and average lake depth to predict average summer water quality conditions such as chlorophyll *a* concentrations, in-lake phosphorus and nitrogen concentrations, water clarity, and lake TSI.

Model Results – Scenario A

Results are discussed below and summarized in Table D-5 for the water quality metrics described previously.

General Observations

The Marine Sea alternatives (Alternatives 5, 6, 7, and 8) exhibit similar changes in thermal stratification as compared to the Recent Conditions simulation. There is a significant increase in the number of days in which the Salton Sea is stratified (described as greater than 2 ˚C [3.6 ˚F]) from 71 in the Recent Conditions simulation to 166 for Alternatives 5 and 6, 98 for Alternative 7, and 140 for Alternative 8, as shown in Table D-5. The extensive increase in stratification under all of the alternatives allows for an increase in the accumulation of hydrogen sulfide and ammonia below the thermocline. Under the No Action Alternative, the water body was sufficiently shallow that thermal stratification is not predicted.

The shallower water bodies (No Action Alternative Phases II through IV, Concentric Rings, Concentric Lakes, and Saline Habitat Complex cells) show a decrease in the summer stratification period, and a general weakening of the stratification as compared to the Recent Conditions simulation.

For the northern Marine Seas in Alternatives 5, 6, and 7 there is a decrease in the number of days with dissolved oxygen concentrations at the water surface of less than 2 mg/L, and a general decrease in average water column dissolved oxygen concentration as compared to Recent Conditions, as shown in Table D-5. As compared to the No Action Alternative, there is a decrease in the number of days of low dissolved oxygen at the surface and a general increase in the average water column dissolved oxygen. Alternative 8 has the highest average dissolved oxygen concentration of any of the alternative simulations and does not exhibit anoxic conditions at the water surface at any time during the year due to the higher winds in the south and shallower average depth of the Marine Sea as compared to the Alternatives 5, 6, and 7. All marine sea alternatives, however, show serious potential for anoxic waters throughout much of the lakes.

The shallow water simulations show an increase in the number of days in which dissolved oxygen concentrations at the water surface are less than 2 mg/L for Saline Habitat Complex and Concentric Lakes compared to Recent Conditions, as shown in Table D-5. As compared to the No Action Alternative, however, the shallow water bodies improve dissolved oxygen conditions. The shallow cells are highly productive. Although the increased algal biomass contributes oxygen to the system during daylight hours, it also demands oxygen through respiration, which severely depresses the dissolved oxygen concentration through the early morning hours with the lowest concentrations assumed at 6 a.m.

Total phosphorus concentrations in Alternatives 3, 4, 7, and 8 and all Saline Habitat Complex cells were higher than in the Salton Sea under Recent Conditions, as shown in Table D-5. Phosphorus concentrations are highest for the shallow water bodies (No Action Alternative in Phases II through IV, Saline Habitat Complex cells, Concentric Rings, and Concentric Lakes). This is directly attributed to the quality of the source water and to the extent of resuspension of bottom sediments predicted in the model. The resuspension contribution is likely an overestimation, but the biological productivity in these water bodies was assumed to be not limited by the availability of phosphorus after implementation of the Marine Sea components.

Annual mean chlorophyll *a* concentrations in Alternatives 5, 6, and 7 are slightly lower than the Recent Conditions simulation. There are noticeable increases in mean annual chlorophyll *a* for Alternative 8 and the No Action Alternative Phases II through IV as compared to Recent Conditions, as shown in Table D-5. The shallow saline water bodies average chlorophyll *a* concentrations are above 100 µg/L (0.10 mg/L). Trophic State Indices are generally higher in the alternatives as compared to Recent Conditions simulation.

Hydrogen sulfide production and accumulation are proportional to the duration and strength of thermal stratification. Model results for No Action Alternative in Phase I indicated lower hydrogen sulfide concentrations than in the Recent Conditions simulation. Alternatives 5, 6, and 7 show increased hydrogen sulfide concentrations at the water surface following lake mixing events compared to Recent Conditions and the No Action Alternative, as shown in Table D-5. Alternative 8 indicates lower hydrogen sulfide concentrations than the Recent Conditions simulation and Phases III and IV of the No Action Alternative. The shallow saline water also shows high hydrogen sulfide concentrations throughout the water column due to a low water volume to sediment area ratio. While there is not significant thermal stratification in the shallow water bodies, the rate of production of hydrogen sulfide from the sediments often exceeds the rate at which it can be oxidized in the water column, thus resulting in higher values near the surface.

No Action Alternative at the End of Phase I (2020)

The Salton Sea under the No Action Alternative at the end of Phase I is considered to be a deep saline water body for the purposes of this analysis. Model results related to temperature, dissolve oxygen, chlorophyll *a*, nutrients as phosphorus and ammonia, and hydrogen sulfide are presented below.

Temperature

The predicted temperature regime for the No Action Alternative at 2020 demonstrates the Salton Sea is generally completely mixed over the entire depth. By year 2020, the depth of the Salton Sea in the No Action Alternative is about 12 meters (39 feet). Metrics indicate that the Salton Sea is never stratified to more than 2 ˚C (3.6 ˚F) over the entire depth, as shown in Figure D-21 and Figures D2-1 through D2-3.

Table D-5
Water Quality Reporting Metrics for Alternatives Simulations

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Bathymetry	Maximum depth (meters)		15.5	12.5	12.5	12.5	14.5	14.75	13.75	2	3
	Average depth (meters)		9.8	7.5	7.5	7.5	9.8	10.6	6.4	2	3
	Water surface area (square kilometers)		940.94	838.54	838.54	838.54	199.55	363.2	254.51	259.32	259.32
	Volume (cubic kilometers)		9.190	6.284	6.284	6.284	1.962	3.854	1.639	5.183	7.774
Salinity assumed for Water Quality Model	Total dissolved solids (mg/L)	35,000	44,000	71,000	197,000	196,000	34,000	35,000	35,000	34,000	35,000
Temperature	Water column annual minimum temperature (°C)		12.4	11.9	10.8	10.7	12.3	12.2	11.3	9.2	9.6
	Water column annual maximum temperature (°C)		32.3	32.6	32.7	33.3	33.3	32.2	32.4	32.6	33.6
	Water column annual mean temperature (°C)		21.9	22.2	22.2	22.2	20.4	21.7	20.2	21.5	21.0

Table D-5
Water Quality Reporting Metrics for Alternatives Simulations

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Temperature	Number of days/year with temperature differences between the top and bottom of the water column greater than 2 °C		71	0	0	0	166	98	140	9	77
	Number of consecutive days/year with temperature differences between the top and bottom of the water column greater than 2 °C		57	0	0	0	144	98	120	8	16
Dissolved oxygen	Number of days/year with dissolved oxygen concentrations at the water surface at 6 a.m. of less than 2 mg/L	0	80	80	321	290	70	60	0	149	102

Table D-5
Water Quality Reporting Metrics for Alternatives Simulations

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Dissolved oxygen	Number of days/year with depth-averaged dissolved oxygen concentration at 6 a.m. of less than 5 mg/L	0	214	284	327	327	267	299	146	324	324
Phosphorus	Annual mean total phosphorus concentration (μg/L)	less than 35	66	118	535	607	64	77	94	1,043	1,066
Nitrogen	Mean ammonia concentration in summer (mg/L)	less than 1	1.5	0.4	2.5	3.1	13.1	4.2	9.7	5.7	7.5
Chlorophyll *a* (in upper portion of water column)	Mean Chlorophyll *a* concentration in summer (μg/L)	less than 12	30	47	135	146	21	34	31	173	178
	Annual mean Chlorophyll *a* concentration (μg/L)		31	46	102	107	30	27	50	116	120
Hydrogen sulfide	Maximum hydrogen sulfide concentration at the water surface (mg/L)	less than 0.05	0.13	0.03	0.11	0.15	0.67	0.53	0.06	0.40	0.75

Table D-5
Water Quality Reporting Metrics for Alternatives Simulations

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Hydrogen sulfide	Number of days/year with water surface hydrogen sulfide concentration greater than 0.05 mg/L	0	6	0	248	265	22	15	1	329	329
Trophic Status	Carlson Trophic State Index	50 to 60	65	73	95	97	64	67	70	104	105

Notes: All values are presented in the units used in the model.
The following conversion factors can be used for the units presented in this table: 1 meter = 3.25 feet, 1 squared kilometers = 242.5 acres, 1 cubed kilometers = 788,065.3 acre-feet, and 1 µg/L = 0.001 mg/L. To convert °C to °F, multiply °C by 1.8 and add 32.

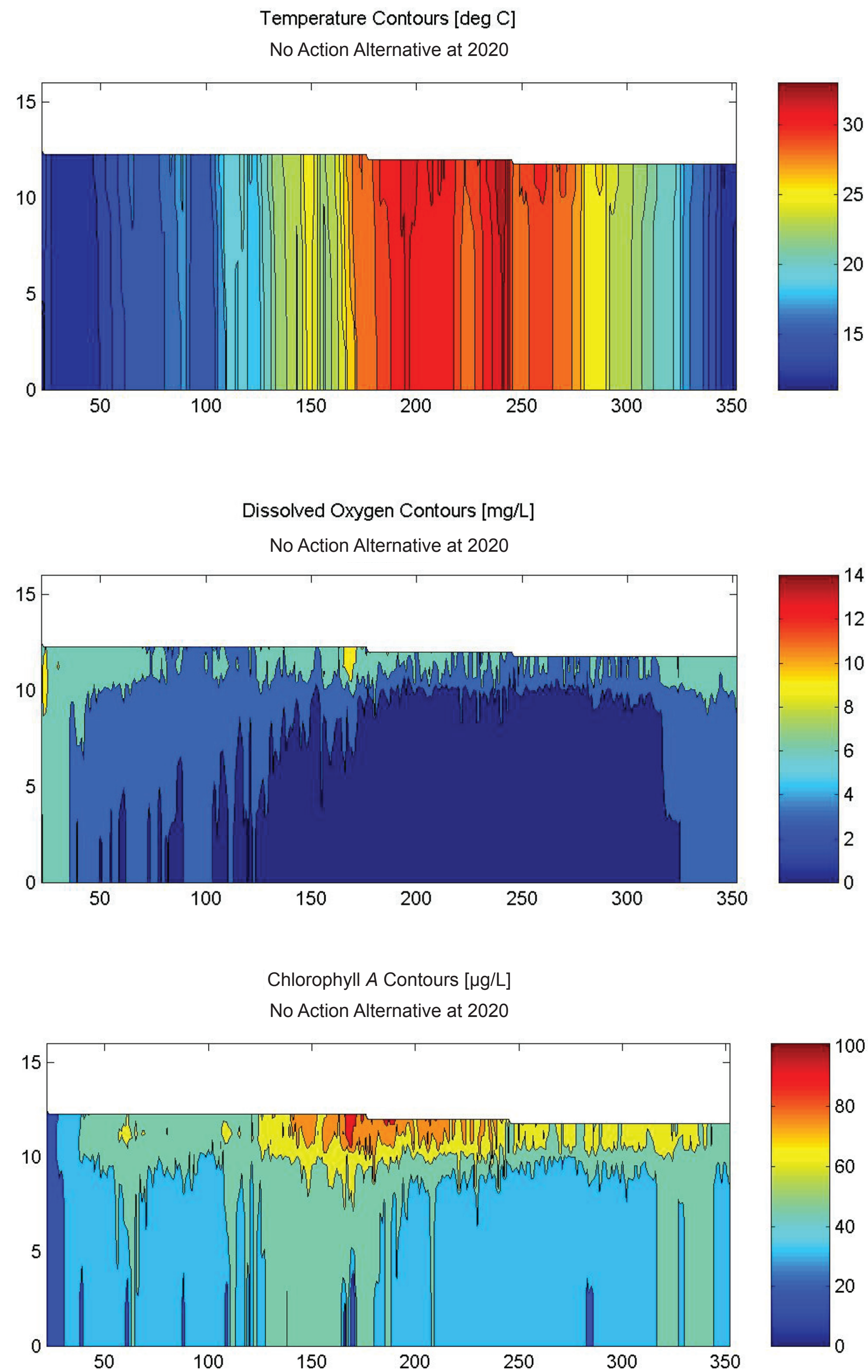


FIGURE D-21
MODELING RESULTS FOR TEMPERATURE, DISSOLVED OXYGEN, AND CHLOROPHYLL *A* FOR THE NO ACTION ALTERNATIVE AT 2020

Dissolved Oxygen

Predicted dissolved oxygen concentration in the No Action Alternative at 2020 simulation are lower on average throughout the water column for the first half of the simulation, then noticeably higher near the water surface for the duration of the simulation, as shown in Figures D-21 and D2-4 through D2-6). The dissolved oxygen concentrations are elevated in the summer and fall periods because of the increase in chlorophyll *a* concentrations in the shallower Salton Sea under the No Action Alternative at 2020 simulation as compared to the Recent Conditions simulation.

Metrics indicate that there are 80 days in which the dissolved oxygen concentration at the water surface is below 2 mg/L at 6 a.m. in both the Recent Conditions simulation and the No Action Alternative at 2020 simulation. There are more days when the Salton Sea depth-averaged dissolved oxygen concentration is below 5 mg/L in the No Action Alternative at 2020 simulation than in the Recent Conditions.

Chlorophyll

Predicted chlorophyll *a* concentrations for the No Action Alternative at 2020 simulation are greater than those under the Recent Conditions simulation, as shown in Figure D-21, D2-7, and D2-8. This increased chlorophyll *a* concentration results in an increase in the daytime dissolved oxygen concentration, as discussed above, and a decrease in the early morning dissolved oxygen concentration. The annual average chlorophyll *a* concentration under the No Action Alternative at 2020 simulation is 46 µg/L (0.046 mg/L), an increase from 31 µg/L (0.031 mg/L) in the Recent Conditions simulation.

Nutrients

There is considerably more orthophosphate throughout the water column in the No Action Alternative at 2020 simulation than in the Recent Conditions simulation. Increased loading of orthophosphate through resuspension of bottom sediments and release of orthophosphate in the pore water is primarily responsible for the increased orthophosphate concentrations. The increase in both chlorophyll *a* and orthophosphate indicates that the algal growth is not as frequently limited by phosphorus for the shallower Salton Sea, as compared to Recent Conditions, because of the increase in internal loading through resuspension. Metrics show that the annual mean total phosphorus concentration for the No Action Alternative at 2020 is 118 µg/L (0.118 mg/L), which is an increase from 66 µg/L (0.066 mg/L) in the Recent Conditions simulation.

The predicted ammonia accumulation in the hypolimnion is substantially lower in the No Action Alternative at 2020 than in the Recent Conditions simulation. The thermally unstratified Salton Sea allows for sufficient mixing and subsequent nitrification of ammonia such that there is no noticeable increase in ammonia concentration in the bottom waters throughout the simulation. Mean summer ammonia concentrations in the Salton Sea are 0.4 mg/L in the No Action Alternative at 2020; a decrease from the 1.5 mg/L under the Recent Conditions simulation.

Hydrogen Sulfide

There is a significant decrease in the hydrogen sulfide concentration in the hypolimnion under the No Action Alternative at 2020 as compared to the Recent Conditions simulation. Since the Salton Sea is well mixed, there is no significant accumulation of hydrogen sulfide in the bottom waters and no subsequent release throughout the water column following the fall turnover. Concentrations at the water surface are slightly lower than those predicted in the Recent Conditions simulation, and the concentration spikes associated with turnover events are noticeably absent in the No Action Alternative at 2020 simulation.

No Action Alternative at the End of Phase III (2040) and End of Phase IV (2078)

The Salton Sea under the No Action Alternative at the end of Phases III and IV is considered to be a shallow saline water body for the purposes of this analysis. Model results related to temperature, dissolved oxygen, chlorophyll *a*, nutrients as phosphorus and ammonia, and hydrogen sulfide are presented below.

Temperature

The predicted temperature regimes for the No Action Alternative at 2040 and 2078 simulations are similar to the No Action Alternative at 2020 simulation with the water column generally completely mixed, as shown in Figures D-22 and D-23. By 2040, the depth of the Salton Sea in the No Action Alternative is nearly half of the depth in 2020, about 6.3 meters (20.5 feet) and never stratified to more than 1.5 ˚C (2.7 ˚F) over the depth, as shown in Figure D2-17.

Dissolved Oxygen

Simulated dissolved oxygen surface concentrations in the No Action Alternative at 2040 and 2078 simulations are significantly lower than those in the No Action Alternative at 2020 simulation, except in summer and fall when higher surface concentrations occur due to increased chlorophyll *a* concentrations during this same period, as shown in Figures D2-20 and D2-36. The extremely low dissolved oxygen concentrations appear to be due to the high oxygen demands of ammonia and hydrogen sulfide as they mix throughout the water column of the smaller Salton Sea. Caution should be used in interpreting these results as the types of algal communities that may be present at the higher salinities of these simulations (equal to or greater than 200,000 mg/L) will likely be significantly different that those for which the model was calibrated. The dissolved oxygen concentrations are related to the productivity level of these communities.

Chlorophyll

Predicted chlorophyll *a* concentrations in the No Action Alternative at 2040 and 2078 simulations are greater than those predicted in the No Action Alternative at 2020 simulation, as shown in Figures D-21, D2-23, and D2-39. Similar to the No Action Alternative at 2020 comparison with the Recent Conditions simulation, the increase in chlorophyll *a* concentration results in an increase in the daytime dissolved oxygen concentration and a decrease in the early morning dissolved oxygen concentration. The annual average chlorophyll *a* concentration for the No Action Alternative at 2040 and 2078 is 135 and 146 µg/L (0.135 and 0.146 mg/L), respectively, which is an increase from the 46 µg/L (0.046 mg/L) in the No Action Alternative at 2020 simulation. The increase in chlorophyll *a* between the No Action Alternative at 2020 and the No Action Alternative at 2040 is due to the increased available phosphorus to support algal growth.

As stated above, caution should be used in interpreting these results as the types of algal communities that may be present at salinities significantly higher than existing would likely be different from those at which the model was calibrated.

Nutrients

There is considerably more orthophosphate throughout the water column in the No Action Alternative at 2040 and 2078 simulations than in the No Action Alternative at 2020 simulation, as shown in Figures D2-25 and D2-41). Many periods throughout the simulation year show an order of magnitude difference in the water column orthophosphate concentration between the two simulations. The model assumes that for the shallower Sea there is increased resuspension of orthophosphate from the bottom sediments and release of orthophosphate in the pore water. Metrics show that the annual mean total phosphorus concentration for the No Action Alternative at 2040 is 535 µg/L (0.535 mg/L), which is a significant increase from the 118 µg/L (0.118 mg/L) in the No Action Alternative at 2020.

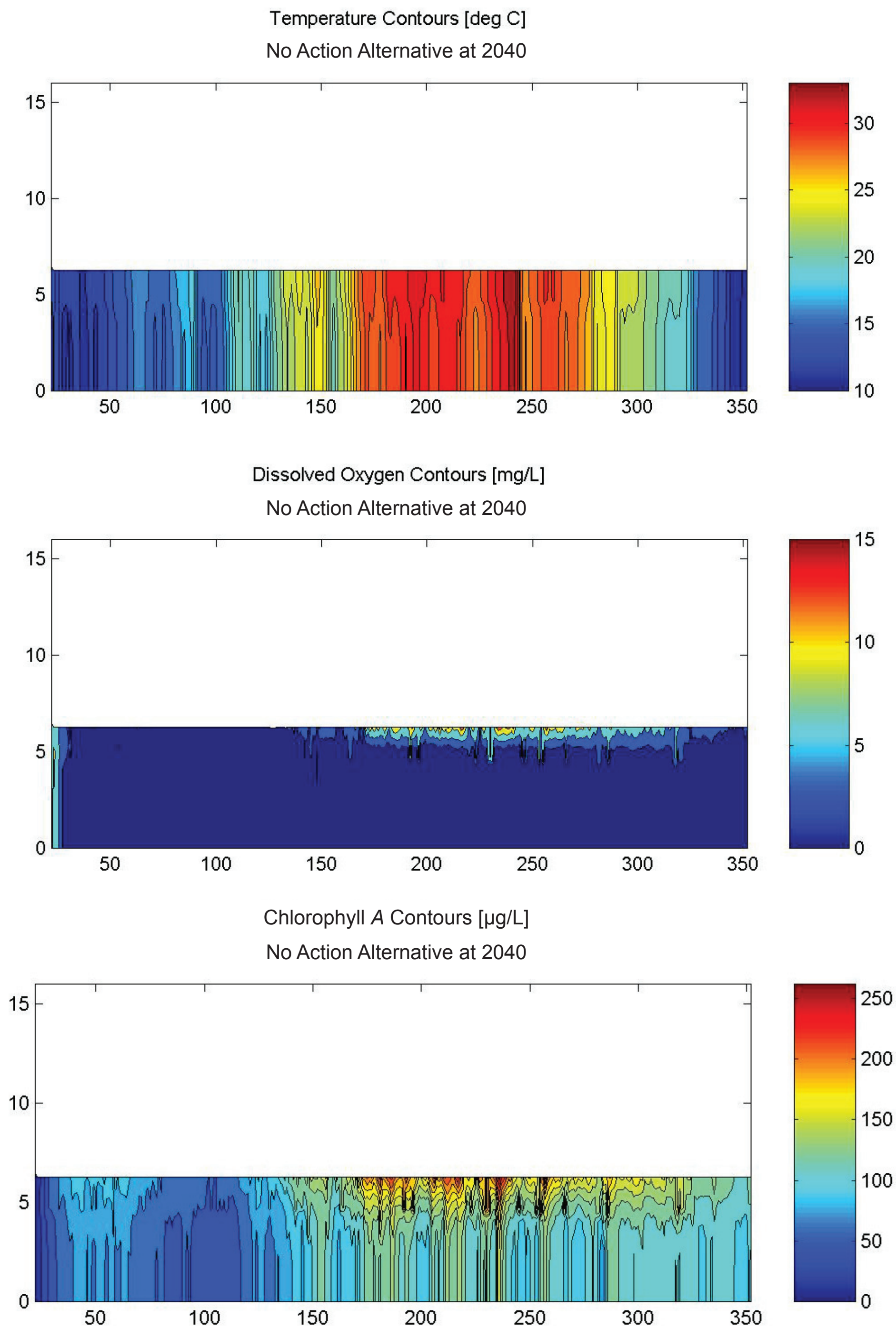
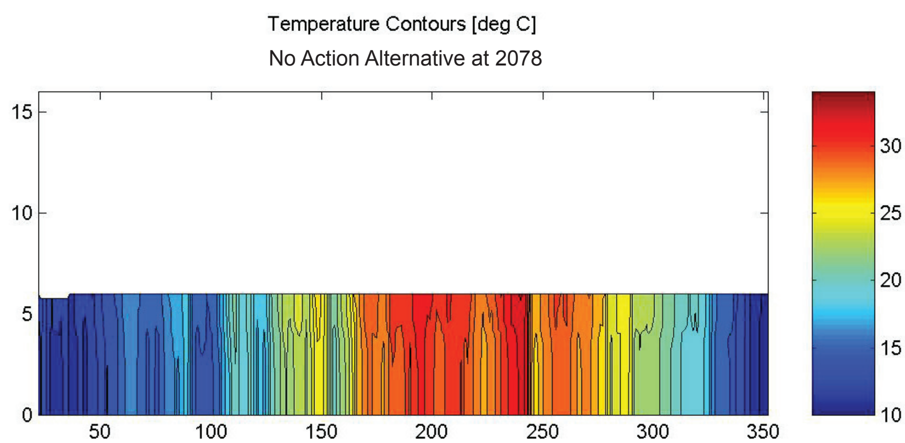
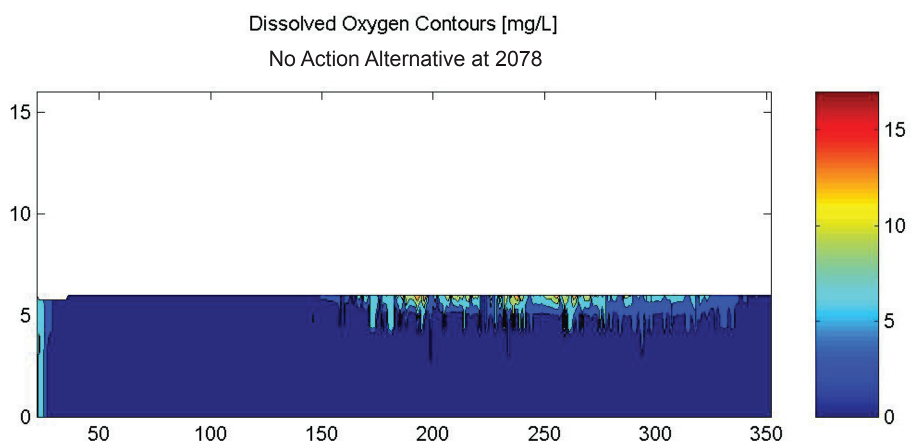


FIGURE D-22
MODELING RESULTS FOR TEMPERATURE, DISSOLVED OXYGEN, AND CHLOROPHYLL *A* FOR THE NO ACTION ALTERNATIVE AT 2040





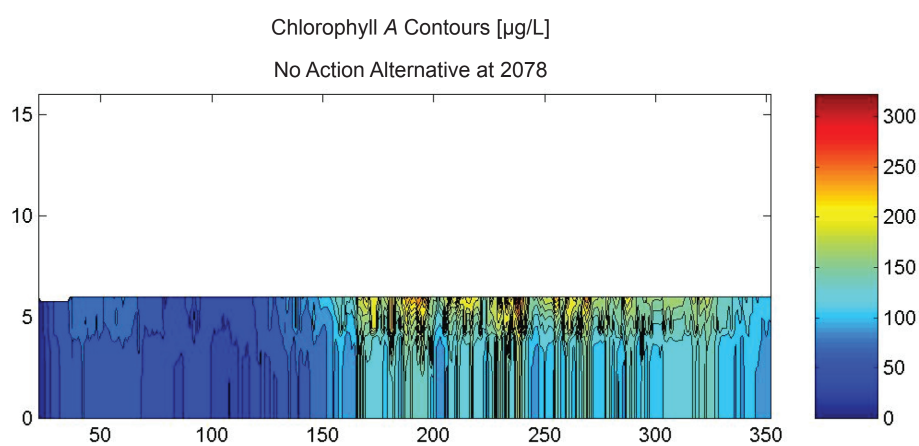


FIGURE D-23
MODELING RESULTS FOR TEMPERATURE, DISSOLVED OXYGEN, AND CHLOROPHYLL *A* FOR THE NO ACTION ALTERNATIVE AT 2078

Ammonia accumulation in the hypolimnion does not occur in the No Action Alternative at 2040 and 2078 simulations, as shown in Figures D2-27 and D2-43. Under these simulations, the shallow Salton Sea is sufficiently mixed such that there is no noticeable increase in ammonia concentration in the bottom waters as compared to concentrations at the water surface throughout the simulation. However, the No Action Alternative at 2040 and 2078 simulations show high ammonia concentrations throughout the water column. These high concentrations result from a high sediment area to volume ratio in which the production of ammonia is high compared to the shallow depth over which the ammonia can be oxidized. Mean ammonia concentrations in the Salton Sea under the No Action Alternative at 2040 and 2078 simulations are up to twice that in Recent Conditions simulation.

Hydrogen Sulfide

As with ammonia concentrations, there is no accumulation of hydrogen sulfide in the hypolimnion in the No Action Alternative at 2040 and 2078 simulations as compared to the No Action Alternative at 2020 simulation, as shown Figures D2-28 and D2-44. In all the No Action Alternative simulations, the Salton Sea is thermally well mixed. However, in the No Action Alternative at 2040 and 2078 simulations, the Salton Sea is shallower than under the No Action Alternative at 2020 so that any release of hydrogen sulfide into the smaller Salton Sea has a larger impact on concentrations at the water surface. Maximum water surface concentrations are similar to concentrations in the Recent Conditions simulation. In comparison with the Recent Conditions simulation, which demonstrated maximum hydrogen sulfide concentrations at the bottom of the water column of about 7 mg/L, the concentrations in the No Action Alternative at 2040 and 2078 simulations are less than 1 mg/L. There is no hypolimnetic accumulation of hydrogen sulfide in the No Action Alternative at 2040 and 2078 simulations, as shown in Figures D2-29 and D2-45.

Marine Sea in Alternatives 5 and 6

The Marine Sea under Alternatives 5 and 6 is considered to be a deep saline water body for the purposes of this analysis. Model results related to temperature, dissolve oxygen, chlorophyll *a*, nutrients as phosphorus and ammonia, and hydrogen sulfide are presented below.

Temperature

The predicted temperature regime for Alternatives 5 and 6 exhibits more pronounced stratification than the Recent Conditions simulation, as shown in Figures D-24 and D2-49. The stratification is both stronger, as defined by a larger difference between temperatures at the water surface and the bottom of the water column, and longer in duration (144 consecutive days versus 57 consecutive days). The combination of a decreased surface area and a lower average wind speed in the northern Marine Sea as compared to the Salton Sea under Recent Conditions result in increased duration of stratification. The reduction in wind speed reduces the evaporative cooling of the surface waters and decreases mixing of warm surface waters into the water column, thus creating a shallower epilimnion and greater temperature difference between the epilimnion and hypolimnion, as shown in Figures D2-50, D2-51A, and D2-51B. This increased stratification leads to accumulation of compounds released from the sediments and decomposition of organic materials in the hypolimnion and at the water-sediment interface, including ammonia and hydrogen sulfide, and a subsequent depression of the dissolved oxygen in the hypolimnion.

Dissolved Oxygen

The predicted dissolved oxygen regime for the Marine Sea in Alternatives 5 and 6 is lower in the hypolimnion, on average, and higher in the epilimnion, on average, than under the Recent Conditions simulation, as shown in Figures D-24 and D2-52. Increased dissolved oxygen in the surface waters is caused by the increased chlorophyll *a* concentration, and the decreased dissolved oxygen in the hypolimnion is likely associated with the increased accumulation of ammonia and hydrogen sulfide in the bottom waters and the oxygen demand associated with oxidation of organic materials, as shown in Figures D2-53, D2-54A, and D2-54B. The noticeable spike in dissolved oxygen in the surface water coincides with a large chlorophyll *a* growth event at Julian Day 130.

The metrics demonstrate that there are slightly fewer days (70 days versus 80 days) in which the dissolved oxygen concentration in the surface waters is below 2 mg/L at 6 a.m. in the Marine Sea under Alternatives 5 and 6 as compared to the Salton Sea in Recent Conditions simulation. The number of days of low surface dissolved oxygen is significantly fewer as compared to the No Action Alternative in Phases II through IV.

Chlorophyll

There is a significant increase in predicted chlorophyll *a* concentration in the surface waters in the Marine Sea in Alternatives 5 and 6 simulation as compared to the Salton Sea in the Recent Conditions, as shown in Figures D-24 and D2-55. This increase results primarily from increased stratification which enables greater production at the surface but reduces the extent of growth. Annual water column average chlorophyll concentrations are actually slightly lower in the Marine Sea in Alternatives 5 and 6, as compared to the Recent Conditions simulation (30 µg/L [0.030 mg/L] versus 31 µg/L [0.031 mg/L]), due to the lower extent of growth.

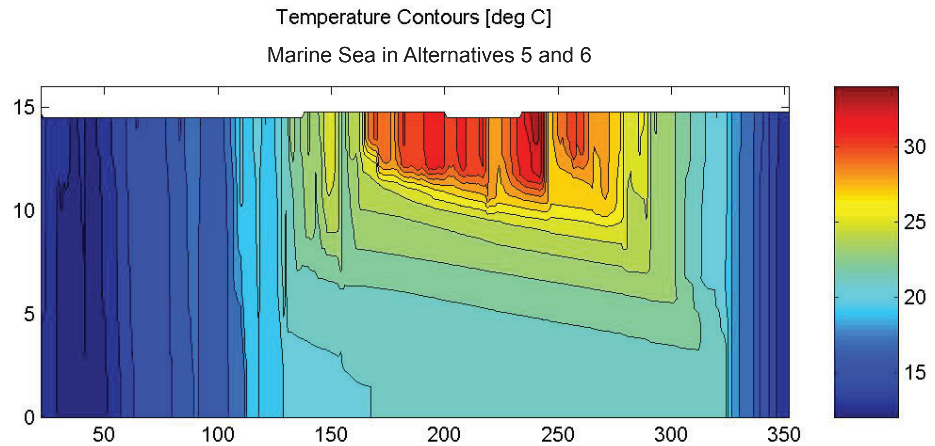
Nutrients

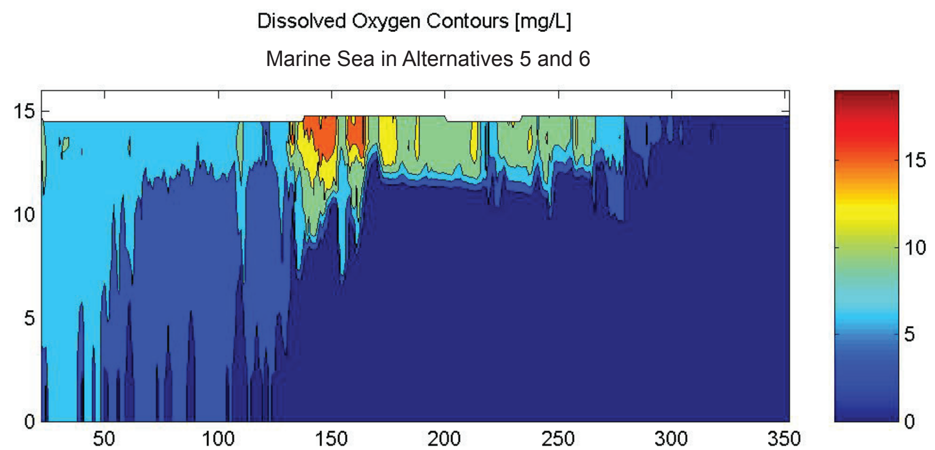
Orthophosphate concentrations follow the same trend in the Marine Sea in Alternatives 5 and 6 as compared to the Salton Sea in the Recent Conditions simulation. The differences that do occur are related to the temporally varying differences in chlorophyll *a* concentration between these two simulations. For the first 125 days of the simulations, there is less chlorophyll *a* and more orthophosphate in the Marine Sea under Alternatives 5 and 6 as compared to the Salton Sea under Recent Conditions. Following the algal bloom on Julian Day 125, there is more chlorophyll *a* and less orthophosphate in the Marine Sea under Alternatives 5 and 6 than the Salton Sea under Recent Conditions, as shown in Figures D2-55 and D2-57. The Salton Sea is primarily phosphorus limited during the spring and summer months in both simulations. It is believed that these results are consistent with previous studies that showed measured values of phosphorus to be lower in the spring and summer.

The annual average total phosphorus concentration is only slightly lower in the Marine Sea under Alternatives 5 and 6 as compared to the Salton Sea under Recent Conditions (64 µg/L [0.064 mg/L] versus 66 µg/L [0.066 mg/L]).

Ammonia concentrations in the hypolimnion start to increase at the onset of stratification once the dissolved oxygen is depleted. Since this occurs earlier in the Marine Sea under Alternatives 5 and 6 than the Salton Sea under Recent Conditions, ammonia accumulates to higher levels than in the Recent Conditions simulation, as shown in Figures D2-58 and D2-59. Peak concentrations at the bottom of the water column approach 30 mg/L in the Marine Sea under Alternatives 5 and 6, about four times the 7 mg/L predicted in Salton Sea under the Recent Conditions simulation. The delayed timing of the entire water column mixing event (Julian Day 325) coupled with the level to which ammonia has accumulated in the hypolimnetic waters, contribute to the inability of the Marine Sea to recover from the depressed dissolved oxygen condition. As shown in Figure D2-59, there is not enough oxygen in the Marine Sea under Alternatives 5 and 6 to completely convert the ammonia to nitrate after the mixing event.

It should be noted that the model assumes an unlimited supply of nutrients because there is no algorithm to simulate a relationship between nutrients in the water column and in the sediment pool. This assumption is useable for the short duration runs and for use in analyses based upon comparison of model runs. For evaluation of long term changes, comparative lake literature was used in the water quality analyses presented in Chapter 6.





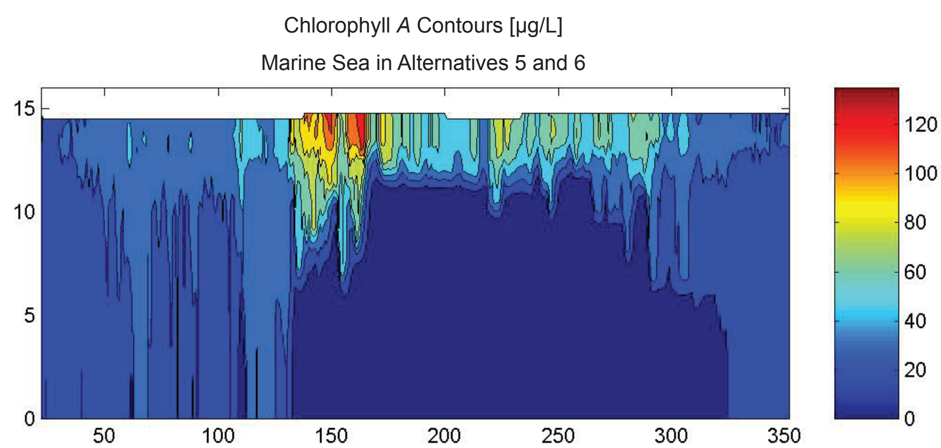


FIGURE D-24
MODELING RESULTS FOR TEMPERATURE, DISSOLVED OXYGEN, AND CHLOROPHYLL *A* FOR THE MARINE SEA IN ALTERNATIVES 5 AND 6

Hydrogen Sulfide

There is a significant increase in accumulation of hydrogen sulfide in the hypolimnion in the Marine Sea of Alternatives 5 and 6 as compared to the Salton Sea under Recent Conditions simulation due to prolonged thermal stratification, as shown in Figure D2-60. Peak hypolimnetic concentrations of hydrogen sulfide are 13.8 mg/L in the Marine Sea under Alternatives 5 and 6, and 7.4 mg/L in the Salton Sea under the Recent Conditions simulation. When the stratification finally breaks down (Julian Da 325), hydrogen sulfide concentrations in the surface waters spike to 0.67 mg/L, or about five times the highest concentration predicted in the Salton Sea under the Recent Conditions Simulation, as shown in Figure D2-61.

Marine Sea Mixing Zone in Alternative 6

The Marine Sea Mixing Zone of this alternative was not specifically analyzed through a model simulation. However, it is expected to perform similar to that described for the Concentric Rings in Alternative 5. Inflows from rivers and drains would be combined with recirculated water from the northern Marine Sea. The shallow water body would be highly productive from a biological standpoint, would not be expected to exhibit thermal stratification, would be more likely to suspend sediments, and would not permit accumulation of hydrogen sulfide and ammonia in the water column. Periods of low dissolved oxygen would be expected, especially during early morning quiescence.

Recreational Saltwater Lake in Alternative 7

The Recreational Saltwater Lake under Alternative 7 is considered to be a deep saline water body for the purposes of this analysis. Model results related to temperature, dissolve oxygen, Chlorophyll *a*, nutrients as phosphorus and ammonia, and hydrogen sulfide are presented below.

Temperature

The predicted temperature regime for the Recreational Saltwater Lake under Alternative 7 exhibits a prolonged period of stratification as compared to the Salton Sea under Recent Conditions simulation, as shown in Figure D-25 and D2-65. Temperature profiles are initially similar in these simulations, but the thermocline breaks down later in the year in Recreational Saltwater Lake under Alternative 7 simulation as compared to the Recent Conditions. The number of consecutive days of stratification increases from 57 days for the Salton Sea in the Recent Conditions simulation as compared to 98 days in the Recreational Saltwater Lake under Alternative 7.

The average wind speed is slightly higher in the Recreational Saltwater Lake under Alternative 7 as compared to the Recent Conditions simulation, but there are less high wind events (area-averaged wind speed more similar to CIMIS station # 127). The thermal stratification is prolonged despite this increase in average wind speed. The surface area of the Recreational Saltwater Lake under Alternative 7 configuration is about 39 percent of the Salton Sea under the Recent Conditions configuration. The decrease in surface area and reduction in high wind events are more important in reducing the mixing energy of the system than the slight increase in average wind speed.

A wind mixing event on Julian Day 225 was sufficient to mix the sea in the Salton Sea under the Recent Conditions simulation, but not sufficient in the Recreational Saltwater Lake under Alternative 7 simulation, which does not mix until Julian Day 280, as shown in Figures D2-66, D2-67A, and D2-67B. This prolonged stratification leads to accumulation of compounds released from breakdown of organic material and the sediments, including ammonia and hydrogen sulfide, and a subsequent depression of the dissolved oxygen in the hypolimnion.

Dissolved Oxygen

The predicted dissolved oxygen regime for the Recreational Saltwater Lake under Alternative 7 is lower in the hypolimnion, on average, and higher in the epilimnion, on average, than the Salton Sea under the Recent Conditions simulation, as shown in Figure D-25 and D2-68. The increased dissolved oxygen in the surface waters during the summer months is caused by the increased chlorophyll *a* concentration (via photosynthesis). The decreased dissolved oxygen in the hypolimnion is likely associated with the increased accumulation of ammonia and hydrogen sulfide, as well as decomposition of organic matter, and the oxygen demand associated with these compounds in the bottom waters, as shown in Figures D2-69, D2-70A, and D2-70B.

The depression of dissolved oxygen in the surface waters for the first 175 days of the simulation corresponds to a significant decrease in predicted chlorophyll *a* concentration throughout the Recreational Saltwater Lake under Alternative 7. The noticeable spike in dissolved oxygen in the surface water coincides with a large chlorophyll *a* growth event (Julian Day 175). Metrics indicate that the dissolved oxygen at the surface is below 2 mg/L slightly less frequently in the Recreational Saltwater Lake under Alternative 7 as compared to the Salton Sea under the Recent Conditions simulation (60 days versus 80 days). However, the Recreational Saltwater Lake under Alternative 7 has lower average dissolved oxygen concentrations than the Salton Sea under the Recent Conditions as measured by the increase in the number of days in which the average dissolved oxygen concentration is below 5 mg/L (299 days versus 214 days).

Chlorophyll

There is a significant increase in predicted chlorophyll *a* concentration in the surface waters in the Recreational Saltwater Lake under Alternative 7 simulation, as shown in Figure D-25 and D2-71 during the summer months (Julian Day 175 to 280). The increase in chlorophyll *a* concentration in the surface waters in the Recreational Saltwater Lake under Alternative 7 as compared to the Salton Sea under the Recent Conditions results primarily from higher phosphorus concentrations in the summer under Alternative 7, as shown in Figure D2-72. The annual average chlorophyll *a* concentration for the Recreational Saltwater Lake under Alternative 7 is actually slightly lower as compared to the Salton Sea in the Recent Conditions simulation (27 µg/L [0.027 mg/L] versus 31 µg/L [0.031 mg/L]).

Nutrients

Orthophosphate concentrations follow the same trend in the Recreational Saltwater Lake under Alternative 7 as compared to the Salton Sea under the Recent Conditions simulation. The differences in orthophosphate are closely related to differences in chlorophyll *a* concentration, as shown in Figures D2-72 and D2-73). Annual average total phosphorus concentrations are slightly higher in the Recreational Saltwater Lake under Alternative 7 as compared to the Salton Sea under the Recent Conditions simulation (77 µg/L [0.077 mg/L] versus 66 µg/L [0.066 mg/L]).

Ammonia concentrations in the hypolimnion accumulate to higher levels in the Recreational Saltwater Lake under Alternative 7 because of the extended period of stratification, as shown in Figures D2-74 and D2-75. Peak concentrations of ammonia at the bottom of the water column approach 15 mg/L in the Recreational Saltwater Lake under Alternative 7, as compared to 7 mg/L predicted in the Salton Sea under the Recent Conditions simulation. The mean summer ammonia concentration increases from 1.5 mg/L in the Salton Sea in the Recent Conditions simulation to 4.2 mg/L in the Recreational Saltwater Lake under Alternative 7.

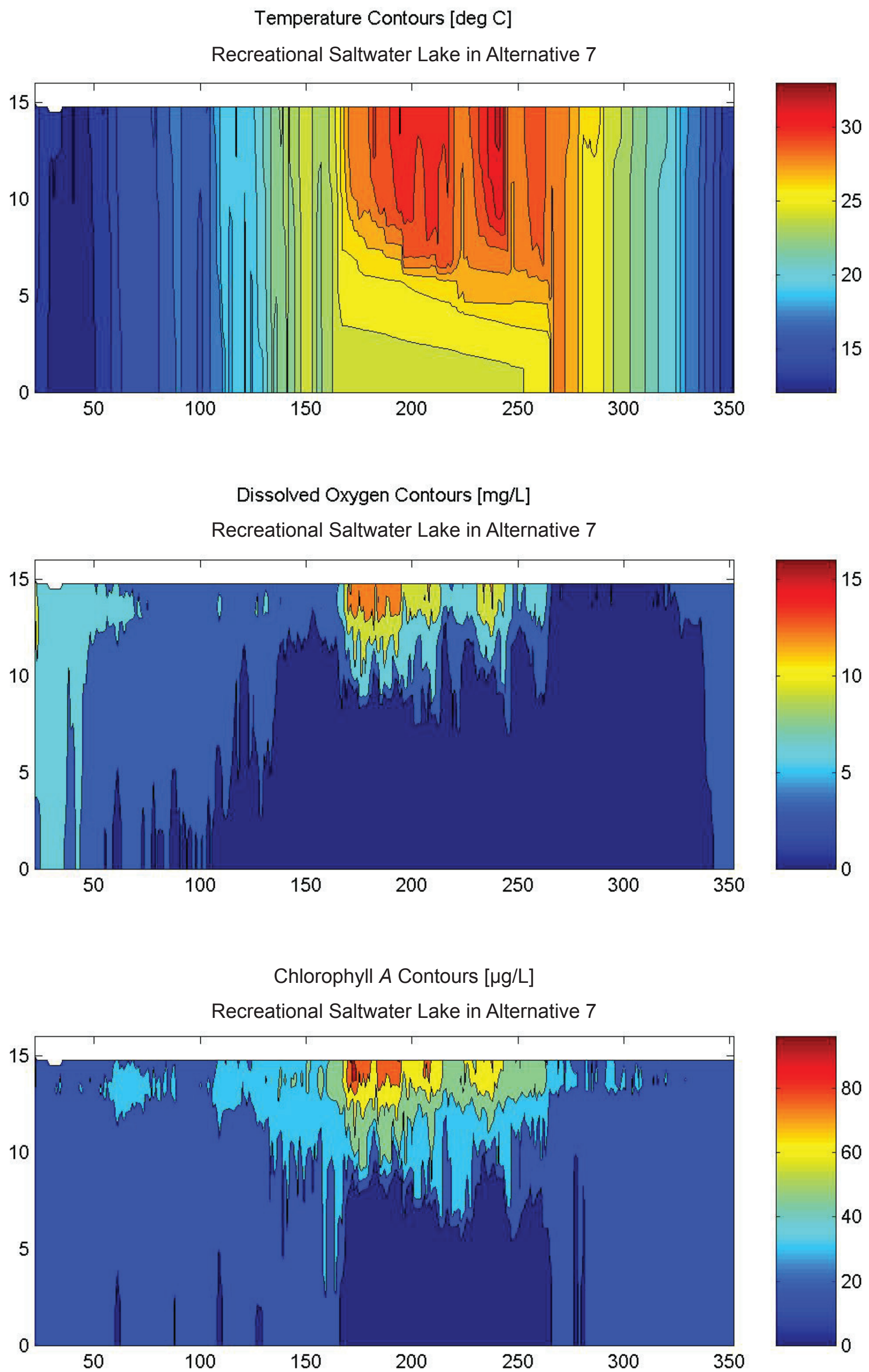


FIGURE D-25
MODELING RESULTS FOR TEMPERATURE, DISSOLVED OXYGEN, AND CHLOROPHYLL *A* FOR THE RECREATIONAL SALTWATER LAKE IN ALTERNATIVE 7

Hydrogen Sulfide

There is a significant increase in accumulation of hydrogen sulfide in the hypolimnion in the Recreational Saltwater Lake under Alternative 7 as compared to the Salton Sea under the Recent Conditions simulation, as shown in Figure D2-76 due to increased thermal stratification. Peak hypolimnetic concentrations of hydrogen sulfide are 13 mg/L in Recreational Saltwater Lake under Alternative 7 and 7.4 mg/L in the Salton Sea under the Recent Conditions simulation. When the stratification breaks down (Julian Day 280), hydrogen sulfide concentration at the water surface spikes to 0.53 mg/L, as shown in Figure D2-77.

Recreational Estuary Lake

The Recreational Estuary Lake of this alternative was not specifically analyzed through a model simulation. However, it is expected to perform similarly to that described for the Concentric Rings in Alternative 5. Inflows from rivers and drains would be combined with recirculated water from the northern Recreational Saltwater Lake. The shallow water body would be highly productive from a biological standpoint, would not be expected to exhibit thermal stratification, would be more likely to suspend sediments, and would not permit accumulation of hydrogen sulfide and ammonia in the water column. Periods of low dissolved oxygen would be expected, especially during early morning quiescence.

Marine Sea in Alternative 8

The Marine Sea under Alternative 8 is considered to be a deep saline water body for the purposes of this analysis. Model results related to temperature, dissolve oxygen, chlorophyll *a*, nutrients as phosphorus and ammonia, and hydrogen sulfide are presented below.

Temperature

The predicted temperature regime for the Marine Sea in Alternative 8 exhibits a more prolonged period of stratification than the Salton Sea in the Recent Conditions simulation, as shown in Figures D-26 and D2-81. The stratification sets up earlier and continues longer in the year in the Marine Sea in Alternative 8 as compared to the Salton Sea in the Recent Conditions simulation. The degree of stratification (temperature difference between top and bottom of the water column) is considerably larger in the late summer to fall period. Metrics indicate the number of consecutive days of stratification increases from 57 to 120 days in the Marine Sea in Alternative 8 as compared to the Salton Sea in the Recent Conditions.

The average wind speed is about 20 percent higher in the Marine Sea in Alternative 8 than the Salton Sea in the Recent Conditions (3.82 meters/second [12.4 feet/second] versus 3.21 meters/second [10.4 feet/second]), but the surface area is considerably smaller for the Marine Sea in Alternative 8 as compared to the Salton Sea in the Recent Conditions. The most noticeable difference in the wind climate for these two simulations occurs at the higher wind speeds. The thermal stratification is prolonged despite this increase in high energy wind events. Therefore, the decrease in surface area is more important in reducing the mixing energy of the system than the increase in average wind speed and frequency of high energy wind events.

The earlier stratification in the Marine Sea in Alternative 8 results in decreased heating of the hypolimnetic waters, as shown in Figure D2-82. Stratification sets up very early in the year (Julian Day 100) and persists a few days before the wind breaks down the stratification. Another, more prolonged stratification event forms around Julian Day 125, and is subsequently broken around Julian Day 150. Finally, the summer stratification develops around Julian Day 160 and persists until Julian Day 300. This prolonged stratification period allows for extensive accumulation of both ammonia and hydrogen sulfide in the hypolimnion.

Dissolved Oxygen

The predicted dissolved oxygen regime for the Marine Sea in Alternative 8 shows consistently higher dissolved oxygen concentrations in the surface water as compared to the Salton Sea in the Recent Conditions simulation, as shown in Figures D-26 and D2-84. The increased dissolved oxygen in the surface water mixes throughout the water column, increasing the bottom concentration as well, as shown in Figure D2-85. The increase in predicted dissolved oxygen in the surface water is associated with increased chlorophyll *a* predicted in this simulation and the higher wind speeds. The model predicts dissolved oxygen concentrations well above saturation during the summer months when chlorophyll *a* concentrations are high. The DLM-WQ model does not allow for off-gassing of dissolved oxygen above saturation concentration, and, therefore, it should be noted that the model over-predicts dissolved oxygen in this simulation.

Metrics indicate that there are no days in which the surface dissolved oxygen concentration drops below 2 mg/L. This is a considerable improvement over the Salton Sea in the Recent Conditions simulation. In addition, there is a decrease in the number of days in which the average dissolved oxygen concentration is less than 5 mg/L (146 days in the Marine Sea in Alternative 8 versus 214 days in the Salton Sea in the Recent Conditions).

Chlorophyll

There is a significant increase in predicted chlorophyll *a* concentration in the surface waters in the Marine Sea in Alternative 8 simulation as compared to the Salton Sea in the Recent Conditions, as shown in Figures D-26 and D2-87. This increase results primarily from increased phosphorus concentrations. Annual average chlorophyll *a* concentrations increased by 77 percent from 31 μg/L (0.031 mg/L) in the Salton Sea in the Recent Conditions simulation to 50 μg/L (0.050 mg/L) in the Marine Sea in Alternative 8. There is a less pronounced increase during the summer months (31 μg/L [0.031 mg/L] versus 30 μg/L [0.030 mg/L]).

Nutrients

Orthophosphate concentrations are significantly higher in the Marine Sea in Alternative 8 as compared to the Salton Sea in the Recent Conditions simulation, as shown in Figure D2-89, despite the significant increase in algal biomass which serves as a sink of orthophosphate. The source of this orthophosphate is increased resuspension predicted by the model associated with higher average winds. Stratification is not related to the resuspension algorithm in the model, therefore, the model assumes that wind-induced resuspension can occur even under stratified conditions (limited to water depths of 10 meters [32.5 feet] or less).

Furthermore, the shallower south subbasin has a greater percentage of the bottom sediments shallower than 10 meters (32.5 feet), which is the threshold in the DLM-WQ for the resuspension on bottom sediments. Therefore, a greater percentage of the bottom sediments are contributing to the internal phosphorus load in the Marine Sea in Alternative 8 than the Marine Seas in Alternatives 5 and 6 or Recreational Saltwater Lake in Alternative 7.

Ammonia begins to accumulate in the hypolimnion earlier in the Marine Sea in Alternative 8 as compared to the Salton Sea in the Recent Conditions simulation, as shown in Figure D2-90. The sequence of thermal stratification and subsequent mixing of the water column contributes to the release and accumulation of ammonia in the hypolimnion until a mixing event. During the main stratification period, ammonia concentrations exceed 25 mg/L in the hypolimnion as compared to 7 mg/L in the Salton Sea in the Recent Conditions simulation, as shown in Figure D2-91. The elevated dissolved oxygen concentrations in the water surface layer provides sufficient oxygen to oxidize the ammonia to nitrate after the water column mixes (Julian Day 310). There is less than 1 mg/L of ammonia throughout the Marine Sea at the conclusion of the Alternative 8 simulation. Depth-averaged water column ammonia concentrations in the summer months increase from 1.5 mg/L in the Salton Sea in the Recent Conditions to 9.7 mg/L in the Marine Sea in Alternative 8.

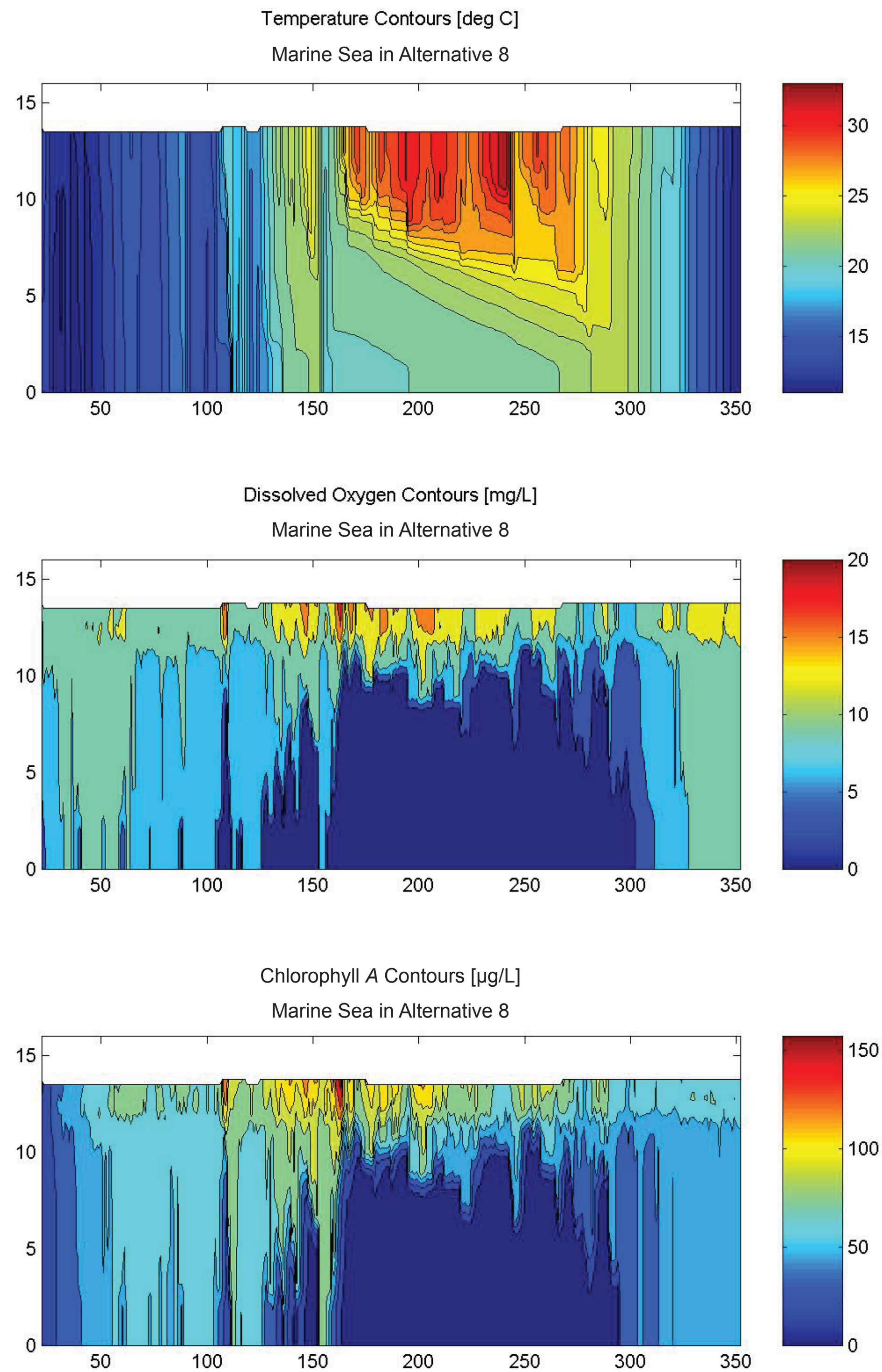


FIGURE D-26
MODELING RESULTS FOR TEMPERATURE, DISSOLVED OXYGEN, AND CHLOROPHYLL *A* FOR THE MARINE SEA IN ALTERNATIVE 8

Hydrogen Sulfide

There is a prolonged duration of hydrogen sulfide accumulation in the hypolimnion due to increased thermal stratification in the Marine Sea in Alternative 8 as compared to the Salton Sea in the Recent Conditions simulation, as shown in Figure D2-92. Peak hypolimnetic concentrations of hydrogen sulfide are similar, with 8 mg/L in the Marine Sea in Alternative 8 as compared to 7.4 mg/L in the Salton Sea in the Recent Conditions. However, the duration of time in which the hypolimnetic concentrations are increasing is nearly doubled in the Marine Sea in Alternative 8 as compared to the Salton Sea in the Recent Conditions.

The increased dissolved oxygen in the Marine Sea in Alternative 8 limits the concentration of hydrogen sulfide in the surface water, and allows the oxidation of hydrogen sulfide as it mixes through the water column following the breakdown of stratification. Peak water surface concentrations of hydrogen sulfide are about half of the concentrations in the Salton Sea in the Recent Conditions simulation, as shown in Figure D2-93.

Saline Habitat Complex Cells and Concentric Lakes in Alternative 4

Saline Habitat Complex cells in Alternatives 1, 2, 5, 6, 7, and 8 and First, Second, Third, and Fourth lakes in Alternative 4 were simulated as shallow individual cells that were 2 meters (6.5 feet) deep with a surface area of 1 square mile (640 acres). The dimensions of the cells for the model were selected prior to development of the final description of alternatives. The Saline Habitat Complex cells in the PEIR alternatives are approximately 3 square miles. However, because the model results should be used in a comparative manner and not as absolute numbers for the impact assessment or for design criteria, the differences in the cell dimensions between the model and the PEIR alternatives are not considered to be problematic.

The Concentric Lakes have similar depths as Saline Habitat Complex cells. The Concentric Lakes do not have complete Berms that cross the water. However, the fetch would be broken by the numerous peninsulas and islands that would be included in the Concentric Lakes.

The shallow depth of these cells in Saline Habitat Complex cells in Alternatives 1, 2, 5, 6, 7, and 8 and First, Second, Third, and Fourth lakes in Alternative 4 provides near complete vertical mixing throughout the simulation. There is only one minor stratification event 8 days in duration.

The shallow cells provide for substantial resuspension of sediments and associated loading of orthophosphate to the water column, contributing to excessive algal productivity. The annual average chlorophyll *a* concentration is 116 μg/L (0.116 mg/L), with concentrations of 173 μg/L (0.173 mg/L) in the summer months.

The simulations for these shallow cells expose a weakness of the DLM-WQ model, which does not allow for off-gassing of supersaturated dissolved oxygen, and thus predicts surface concentrations of dissolved oxygen in excess of 40 mg/L. In addition, the modeling assumes the identical sediment phosphorus concentrations for all areas of the Sea Bed. Sediment phosphorus concentrations, however, are not evenly distributed and Anderson and Amrhein (2002) suggest lower concentrations in the shallow areas. This is a limitation in the modeling effort. However, modeling suggests that the shallow water bodies are not phosphorus limited; an indication that the high sediment phosphorus concentrations assumed in the model may not significantly impact the results. These limitations, however, reinforce the concept that the model results should only be evaluated in a comparative manner.

The predictions of the DLM-WQ model must be interpreted with caution considering known limitations of the model, including assumptions of internal loading. The model accounts for both particulate phosphorus and orthophosphate during resuspension, but assumes that only orthophosphate is available for any biological growth, including algal growth. This limitation and the previously discussed limitations of the model are not problematic if the model results are used only in a comparative manner.

The model results indicate that the small, shallow cells with high phosphorus would be extremely productive. These results are based upon the assumption in the model that phosphorus continues to be provided by the New and Alamo rivers inflows, and that the phosphorus concentrations are the same in the rivers and the shallow cells. Information for the Brawley wetlands is consistent with the inter-day fluctuations in dissolved oxygen predicted by the DLM-WQ model.

Despite the modeling limitations for this alternative, several features of these shallow cells can be estimated. First, the warm, shallow, nutrient rich water column would likely see excessive algal growth and supersaturated dissolved oxygen concentrations during the daytime hours when photosynthesis is contributing to the dissolved oxygen concentration. Early morning dissolved oxygen concentrations may be significantly depressed as the algal population respires and consumes oxygen. Orthophosphate in the water column is expected to be controlled by the source water quality and the ease of resuspending sediments in such a shallow system. Finally, the well mixed water column would preclude the accumulation of ammonia and hydrogen sulfide. However, due to the shallow depth, the continuous presence of hydrogen sulfide and ammonia throughout the water column may exist.

The EUTROMOD model was applied for these shallow cells to confirm the general findings of the DLM-WQ analysis. EUTROMOD results indicate that the Saline Habitat Complex cells would likely be hypereutrophic in character. Water clarity would be expected to be less than a foot, with high chlorophyll values (greater than 22 µg/L (0.022 mg/L) and TSI values in the hypereutrophic range (greater than 70) if the inflows to the cells are any combination of water from the rivers and drains. EUTROMOD results also suggest the cells have some potential for high oxygen demand and dissolved oxygen depletion during overnight and windless periods. Such cells typically experience a high degree of daily oxygen and pH fluctuations (with lowest pH and dissolved oxygen levels at night due to biota activity).

Concentric Rings in Alternative 3

The First and Second rings in Alternative 3 were modeled as individual cells that were 3 meters (9.75 feet) deep with a surface area of 1 square mile (640 acres). It is recognized that the Concentric Rings would have long areas that would increase fetch as compared to small cells. However, due to the depth of water of about 3 meters, it was determined that the Marine Sea portion of the model would not be appropriate for the Concentric Rings. Due to limited amount of time for the development of the model, it was not feasible to develop another model simulation for the Concentric Rings within the schedule for preparation of the PEIR. Therefore, because the model should only be used in a comparative manner, it was determined that the model results for the smaller shallow cells could be used to be indicative of conditions in the Concentric Rings. However, the model values should not be used for design criteria without additional evaluations.

These rings are considered to be shallow water bodies that are primarily well mixed, but do show numerous short term episodes of significant stratification. There are a total of 77 days in which the thermal stratification exceeds 2 ˚C (3.6 ˚F), but the longest continuous stratification event is only 16 days. Results are very similar to those discussed above for the Saline Habitat Complex cells and Concentric Lakes in Alternative 4 with regards to algal productivity and daily variations in dissolved oxygen. The shallow rings are very productive, with annual average chlorophyll *a* concentrations of 120 µg/L (0.120 mg/L) and average summer concentrations of 178 µg/L (0.178 mg/L). The algal biomass causes excessive dissolved oxygen concentrations during the daylight hours and extremely low dissolved oxygen concentrations in the early morning hours. These values are subject to the same model limitations for shallow water bodies discussed above.

Table D-6
Water Quality Reporting Metrics for Alternatives Simulations with 50 Percent Phosphorus Load Reduction

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Bathymetry	Maximum depth (meters)		15.5	12.25	12.25	12.25	14.5	14.75	13.75	2	3
	Average depth (meters)		9.8	7.5	7.5	7.5	9.8	10.6	6.4	2	3
	Water surface area (square kilometers)		940.94	838.54	838.54	838.54	199.55	363.2	254.51	259.32	259.32
	Volume (cubic kilometers)		9.190	6.284	6.284	6.284	1.962	3.854	1.639	5.183	7.774
Salinity assumed for Water Quality Model	Total dissolved solids (mg/L)	35,000	44,000	71,000	197,000	196,000	35,000	35,000	35,000	34,000	35,000
Temperature	Water column annual minimum temperature (^{o}C)		12.4	11.9	10.8	10.6	12.3	12.2	11.3	9.2	9.6
	Water column annual maximum temperature (^{o}C)		32.3	32.5	32.7	32.7	32.9	32.2	32.3	32.6	33.5

Table D-6
Water Quality Reporting Metrics for Alternatives Simulations with 50 Percent Phosphorus Load Reduction

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Temperature	Water column annual mean temperature (°C)		21.9	22.2	22.0	22.0	20.2	21.7	20.8	21.5	21.0
	Number of days/year with temperature differences between the top and bottom of the water column greater than 2 °C		71	0	0	0	177	108	112	1	79
	Number of consecutive days/year with temperature differences between the top and bottom of the water column greater than 2 °C		57	0	0	0	176	108	81	1	16

Table D-6
Water Quality Reporting Metrics for Alternatives Simulations with 50 Percent Phosphorus Load Reduction

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Dissolved oxygen	Number of days/year with dissolved oxygen concentrations at the water surface at 6 a.m. of less than 2 mg/L	0	80	66	139	125	27	31	0	18	34
Dissolved oxygen	Number of days/year with depth-averaged dissolved oxygen concentration at 6 a.m. of less than 5 mg/L	0	214	147	293	301	213	179	128	183	208
Phosphorus	Annual mean total phosphorus concentration (μg/L)	less than 35	66	59	277	306	32	37	46	515	541
Nitrogen	Mean ammonia concentration in summer (mg/L)	less than 1	1.5	0.1	0.5	0.6	5.8	1.7	2.7	0.7	1.9

Table D-6
Water Quality Reporting Metrics for Alternatives Simulations with 50 Percent Phosphorus Load Reduction

Parameter	Metric[a]	Target Value	Recent Conditions (similar to Existing Conditions)	No Action Alternative-Variability Conditions			Marine Sea Habitat @ 35,000 mg/L			Shallow Water	
				Phase I (at 2020)	Phase III (at 2040)	Phase IV (at 2078)	Alts. 5 and 6	Alt. 7	Alt. 8	Saline Habitat Complex cells in Alts. 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alt. 4	Concentric Rings in Alt. 3
Chlorophyll *a* (in upper portion of water column)	Mean Chlorophyll *a* concentration in summer (μg/L)	less than 12	30	30	150	170	11	17	15	296	212
	Annual mean Chlorophyll *a* concentration (μg/L)		31	40	132	146	21	21	35	250	186
Hydrogen sulfide	Maximum hydrogen sulfide concentration at the water surface (mg/L)	less than 0.05	0.13	0.01	0.02	0.02	0.33	0.21	0.08	0.13	0.34
Hydrogen sulfide	Number of days/year with water surface hydrogen sulfide concentration greater than 0.05 mg/L	0	6	0	0	0	6	10	2	328	248
Trophic Status	Carlson Trophic State Index	50 to 60	65	63	85	87	54	56	59	94	95

Notes: All values are presented in the units used in the model.
The following conversion factors can be used for the units presented in this table: 1 meter = 3.25 feet, 1 squared kilometers = 242.5 acres, 1 cubed kilometers = 788,065.3 acre-feet, and 1 μg/L = 0.001 mg/L. To convert °C to °F, multiply °C by 1.8 and add 32.

Model Results – Scenario B

Modeling results using the assumptions described for Scenario B are discussed below and summarized in Table D-6 for the water quality metrics described previously. Contour and time series plots for both temperature and dissolved oxygen results are contained in Appendix D3.

The reduction in both internal and external phosphorus loads leads to a reduction in the average annual total phosphorus concentration, and, therefore, a reduction in the chlorophyll *a* concentration and the TSI for the deep water bodies. Average annual total phosphorus and chlorophyll *a* concentration changes based on simulations without and with the reductions in external/internal loads are as follows:

- Marine Sea in Alternative 5 and 6: Phosphorus: 64 to 32 µg/L (0.064 to 0.032 mg/L), chlorophyll *a*: 30 to 21 µg/L (0.030 to 0.021 mg/L);
- Recreational Saltwater Lake in Alternative 7: Phosphorus: 77 to 37 µg/L (0.077 to 0.037 mg/L), chlorophyll *a*: 27 to 21 µg/L (0.027 to 0.021 mg/L);
- Marine Sea in Alternative 8: Phosphorus: 94 to 46 µg/L (0.094 to 0.046 mg/L), chlorophyll *a*: 50 to 35 µg/L (0.050 to 0.035 mg/L);
- Salton Sea in No Action Alternative at 2020: Phosphorus: 118 to 59 µg/L (0.118 to 0.059 mg/L), chlorophyll *a*: 46 to 40 µg/L (0.046 to 0.040 mg/L);
- Salton Sea in No Action Alternative at 2040: Phosphorus: 535 to 277 µg/L (0.535 to 0.277 mg/L), chlorophyll *a*: 102 to 132 µg/L (0.102 to 0.132 mg/L);
- Concentric Rings in Alternative 3: Phosphorus: 1066 to 541 µg/L (1.066 to 0.541 mg/L), chlorophyll *a*: 120 to 186 µg/L (0.120 to 0.186 mg/L); and
- Saline Habitat Complex cells in Alternatives 1, 2, 5, 6, 7, and 8, and Concentric Lakes in Alternative 4: Phosphorus: 1043 to 515 µg/L (1.043 to 0.515 mg/L); chlorophyll *a*: 116 to 250 µg/L (0.116 to 0.25 mg/L).

For the deep saline water bodies, of DLM-WQ model simulations under Scenario B assumptions of a 50% reduction in external loads (and internal loads at equilibrium) show a decrease in total phosphorus concentrations (~50%), decrease in chlorophyll a concentrations (~30%), a decrease in trophic state (i.e., an improvement in water quality), and a decrease in the low dissolved oxygen episodes in the surface waters. Consistent with previous findings by other researchers (Setmire et. al., 2001; Schladow, 2004), the modeling indicates that a reduction in external loads of greater than 50% will be required to achieve the eutrophication goals.

For the shallow water bodies, there is a decrease in total phosphorus concentration commensurate with the reduction in load. However, model simulations suggest an increase in depth-averaged mean chlorophyll *a* concentrations. There is an increase in the average chlorophyll *a* concentration from 120 to 186 µg/L (0.120 to 0.186 mg/L) in the Concentric Rings of Alternative 3 and from 116 to 250 µg/L (0.116 to 0.25 mg/L) in the Saline Habitat Complex cells of Alternatives 1, 2, 5, 6, 7, and 8 and Concentric Lakes in Alternative 4.

The model suggests that the increase in chlorophyll a concentrations is primarily caused by a reduction in the light limitation due to the assumed reduction in particulate material from the inflow streams. It should be noted that the shallow water bodies did not exhibit phosphorus limitations to algal growth in either scenario.

There is a general increase in water surface dissolved oxygen with the reduction in phosphorus loads. The number of days in which the dissolved oxygen at the water surface is below 2 mg/L decreases with the reduction in phosphorus loads as compared to the model run results without external and internal load reductions. The reductions in days with dissolved oxygen equal to or less than 2 mg/L at the water surface are as follows:

- Marine Sea in Alternatives 5 and 6: 73 to 27 days;
- Recreational Saltwater Lake in Alternative 7: 60 to 31 days;
- Marine Sea in Alternative 8: (no change, 0 days in both simulations);
- No Action Alternative at 2020: 80 to 66 days;
- Saline Habitat Complex cells and Concentric Lakes: 149 to 18; and
- Concentric Rings: 102 to 34 days.

In general, the reduction in phosphorus loads has little impact on the thermal stratification of the deep saline water bodies, as shown in Table D-6. The number of stratified days is reduced slightly as external and internal loadings are reduced.

Model Results – Scenario C

Modeling results using the assumptions described for Scenario C are discussed below. Contour and time series plots for both temperature and dissolved oxygen results are contained in Appendix D3.

The reduction in both internal and external phosphorus loads leads to a reduction in the average annual total phosphorus concentration, and, therefore, a reduction in the chlorophyll *a* concentration and the TSI for the deep water bodies. Average annual total phosphorus and chlorophyll *a* concentration changes in the Recreational Saltwater Lake in Alternative 7, based on simulations without and with the reductions in external/internal loads, are as follows:

- Phosphorus: 77 to 8 µg/L (0.077 to 0.008 mg/L); and
- chlorophyll *a*: 27 to 4 µg/L (0.027 to 0.004 mg/L).

Under the Scenario C assumptions of a 90 percent reduction in external loads (and internal loads at equilibrium), simulations show a decrease in total phosphorus concentrations (~90 percent), decrease in chlorophyll a concentrations (~85 percent), a decrease in trophic state (i.e., an improvement in water quality), and a decrease in the low dissolved oxygen episodes in the surface waters. Under the aggressive nutrient controls and internal response assumptions of this scenario, it appears possible to achieve the SWRCB's eutrophication goals.

There is a general increase in water surface dissolved oxygen with the reduction in phosphorus loads. The number of days in which the dissolved oxygen at the water surface is below 2 mg/L decreases to zero with the aggressive reduction in phosphorus loads as compared to the model run results without external and internal load reductions. As under Scenario B, the reduction in phosphorus loads has little impact on the thermal stratification of the Recreational Saltwater Lake.

Again, it must be stressed that both aggressive watershed controls and inflow treatment would need to be implemented to achieve the inflow quality assumptions of this scenario. Also, the timing of lake response to external load reductions is not expected to be linear, such that the large reductions in external nutrient loads generally translate into longer time periods to reach a new equilibrium.

SUMMARY AND DISCUSSION

The Salton Sea is a highly eutrophic terminal lake that suffers from significant water quality problems. The eutrophic conditions at the Salton Sea are largely controlled by the biologically-essential nutrients supplied to the water body from both external and internal sources. The high productivity has contributed to a number of impairments to water quality, including nuisance algal blooms, anoxia, production of hydrogen sulfide and ammonia, and serious detrimental effects to fish. The eutrophic condition of the Salton Sea is believed to be controlled, or limited, by phosphorus concentrations. Numerical modeling has been performed to better understand the relative importance of processes governing the eutrophic conditions at the Salton Sea, and to provide comparative information on the range of future water quality conditions under a range of water body configurations and nutrient loading scenarios.

General Conclusions

The DLM-WQ model has been applied to study the hydrodynamic and water quality conditions at the Salton Sea. The model was calibrated using observed water quality data from Holdren and Montaño (2002) for 1999. Temperature, dissolved oxygen, nutrients, and chlorophyll *a* were included in the calibration. A hydrogen sulfide algorithm was incorporated into the model specifically for this study to allow for an approximate assessment of the potential deleterious effects of bottom water hydrogen sulfide accumulation, severe anoxia, and oxidation throughout the water column upon mixing. The model calibration provided a good match to measured profiles of both dissolved oxygen and temperature with several adjustments as described in this appendix.

Time series observations of orthophosphate, ammonia, nitrates, and chlorophyll *a* were also reproduced reasonably well by the model. Comparison of the temperature results from the one-dimensional DLM-WQ model and the three-dimensional SI3D model for identical conditions at the Salton Sea are very similar, both in terms of the degree and length of stratification, suggesting that the one-dimensional assumption is not a significant limitation for the approximate analysis of *comparing* alternatives.

The DLM-WQ model calibration results confirm that the water quality conditions in the Salton Sea are strongly linked to thermal structure. Periods of higher winds and cooler temperatures allow for greater mixing of the water column and higher sea-average dissolved oxygen conditions. Intense and continuous stratification allows for bottom water accumulation of ammonia, hydrogen sulfide, and other constituents in the water column that utilize oxygen which can cause hypolimnetic anoxia. Mixing, after prolonged periods of thermal stratification, is often associated with very low dissolved oxygen levels throughout the water column. These conditions have been linked with some fish kills.

Phosphorus has previously been identified as the limiting nutrient for biological production in the Salton Sea. The primary sources of phosphorus to the Salton Sea are from rivers and drains (external sources), and from internal sediment release and resuspension processes. Model calibration suggests that resuspension of phosphorus may be the most significant load to the Salton Sea. Calibration of orthophosphate and chlorophyll *a* portions of the model could not be achieved without the consideration of a significant internal source in addition to sediment release. Because of this limitation and others discussed in this appendix, it is restated that this model should not be used to develop absolute values, and should only be used in a comparative manner to define trends in the implementation of the alternatives as compared to Recent Conditions and No Action Alternative.

The DLM-WQ model was applied to the deep and shallow saline water bodies in the PEIR alternatives. Conclusions from simulations regarding the deep, saline water bodies in Alternatives 5, 6, 7, and 8 are listed below:

- The deep Marine Seas in Alternatives 5, 6, and 7; Recreational Saltwater Lake; and the Salton Sea under the No Action Alternative at 2020 tend to stratify more than the Salton Sea under Recent Conditions;
- The northern deep water bodies (Marine Seas in Alternatives 5 and 6 and the Recreational Saltwater Lake in Alternative 7) tend to stratify more deeply and for a greater duration than the

Marine Sea in the southern subbasin under Alternative 8 due to greater average depths and lower winds in the northern subbasin;

- All deep Marine Seas (Alternatives 5, 6, and 8), the Recreational Saltwater Lake (Alternative 7), Salton Sea under No Action Alternative at 2020, and Salton Sea under Recent Conditions exhibit the potential for anoxic waters throughout much of the water column;
- Dissolved oxygen near the water surface is slightly increased in the Marine Seas, Recreational Saltwater Lake, and the Salton Sea under the No Action Alternative at 2020 as compared to the Salton Sea under Recent Conditions, with the greatest change in the Marine Sea in the southern subbasin in Alternative 8 in which the water surface dissolved oxygen was always greater than 2 mg/L;
- The potential exists to increase the portion of the Marine Seas and Recreational Saltwater Lake with dissolved oxygen greater than 2 mg/L, while not reducing phosphorus or chlorophyll *a* concentrations, especially for water bodies in the southern Sea Bed; and
- Maximum surface hydrogen sulfide concentration is expected to increase in the Marine Seas and Recreational Saltwater Lake water bodies in the northern subbasin, and decrease in the Marine Sea in the southern subbasin.

Conclusions from simulations of the shallow water bodies (Saline Habitat Complex cells, Concentric Rings, and Concentric Lakes) are summarized below:

- The shallow water bodies show a decrease in the summer stratification period, and a general weakening of the stratification when it does occur. With water depths less than 2 meters (6.5 feet) depth, the water body is virtually continuously unstratified;
- Biological productivity is expected to be very high in all shallow water bodies, potentially with chlorophyll *a* concentrations greater than 100 to 200 µg/L (0.1 to 0.2 mg/L);
- Resuspension is likely to be a significant factor in the shallow water bodies as wind mixing energy can more easily suspend sediments; and
- Dissolved oxygen would show significant swings from supersaturation due to photosynthesis during the day to less than 2 mg/L in the early morning due to nighttime respiration (which appears to be consistent with observations at the Brawley and Imperial Wetlands).

Uncertainty exists with respect to the response of the Salton Sea sediments to reductions in external nutrient loads, including differing results in the short term and long term periods. Therefore, three sets of model simulations were developed to provide a "bookend" type analysis. One model simulation represented conditions without reductions in river and drain nutrient concentrations (Scenario A). The second model simulation represented a 50 percent reduction in inflow nutrient concentrations and an equivalent reduction in internal sediment release and resuspension rates/concentrations (Scenario B). Finally, a third model simulation, applied only to Alternative 7, represented a 90 percent reduction in inflow nutrient concentrations and an equivalent reduction in internal sediment release and resuspension rates/concentrations (Scenario C). All simulations with both external and internal load reductions showed a reduction in phosphorus concentrations in the water bodies. In the deep, Marine Sea, Recreational Saltwater Lake, and Salton Sea under the No Action Alternative at 2020, chlorophyll *a* concentrations and TSI showed a substantial reduction.

Limitations and Uncertainty

Limitations and uncertainty associated with the data, models, and understanding of the system dynamics exist in this analysis. For example, only 1 year of complete temperature and water quality data exists from which to begin model development and calibration; the DLM-WQ model is lacking a fully-coupled sediment-water algorithm; and the long term fate and sequestration of phosphorus in the deep saline water bodies is not well understood. In addition, the model underpredicts dissolved oxygen and re-aeration following mixing by winds, and likely overpredicts the dissolved oxygen where chlorophyll *a* concentrations are high. It was necessary to calibrate with a high sediment oxygen demand in order to achieve a suitable match with measured hypolimnetic oxygen concentrations, but some of this oxygen demand could be from decomposition of algae in the water column near the water-sediment interface rather than solely a sediment source. Given these and other uncertainties, the model results and analysis should be used in comparative mode rather than as predictive results.

Data limitations and uncertainties consist of the lack of water column profiles of hydrogen sulfide, interpolation of complex wind-fields from point measurements (and uncertainty regarding the obstructional effects on these data), observed data quality and spatial variability, and overall lack of field data. The primary limitations with the model are the one-dimensional assumption, lack of dynamic coupling of the sediment with the water column parameters, simplified hydrogen sulfide algorithms, and inability to remove supersaturated dissolved oxygen from the water column. In addition, large values of SOD were required for calibration.

Despite significant uncertainty, the model can serve as a useful tool for comparative analysis, incorporating the best understanding of the physical system. The model also can guide and focus future data collection efforts, including the following items:

- Long term water quality monitoring of the Salton Sea and tributary sources at a frequency useful for capturing system dynamics, including weekly monitoring of Salton Sea nutrients and chlorophyll *a* and real-time temperatures;
- Focused data collection to better understand the role of sediment resuspension, sediment release, nutrient sequestration, and SOD;
- Pilot studies of shallow water cells on recently exposed Sea Bed to determine the rate of nutrient fluxes to the water column and other biological parameters that may be different on the Sea Bed materials as compared to pilot studies being conducted on lands adjacent to the Sea Bed;
- Development of a multi-dimensional hydrodynamic and water quality model, including a coupled sediment pool, for the Salton Sea that could be used, in tandem with data collection efforts, to provide more detailed analysis of specific facility locations; and
- Investigate the salinity level necessary to maintain high levels of calcite precipitation and co-precipitation of phosphorus and hydroxyapatite for phosphorus control, while maintaining a salinity that will sustain a marine fishery.

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